Household investment in home energy retrofit

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Title

Household investment in home energy retrofit: a review of the evidence on effective public policy design for privately owned homes

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Abstract

Home energy retrofit is distinctive as a low carbon policy option because it often requires collaboration between private households and public policy in the deeply personal environment of the home. While there is a strong case for public investment in retrofit there is also a strong case for private investment, and as a result there is often a joint public-private contribution to its costs. This paper reports the results of a systematic evidence review and synthesis on policy effectiveness for private household investment in energy retrofit. The review considered how public policy can be used to effectively and efficiently leverage private household investment, across both demand-side and supply-side aspects. On the demand-side, the results show policy interventions leverage a wide range of private funding, from well below public funds, to several multiples of them. At the same time, calculating leverage is not straightforward, but involves various additionality, positive spill-over and market effects. In terms of different policy tools, subsidised loans offer the highest private to public leverage ratios, but are less attractive to households – and are less widely used – than one-off payment grants and tax incentives. The review highlights inadequate policy attention on the role of the supply-side in retrofit policy making, with missed opportunities for improved retrofit performance and sales. The paper also considers the effectiveness of the overall policy mix, in terms of stability, flexibility and simplicity. Finally, understanding policy effectiveness in complex systems such as household retrofitting requires a broad and realist approach to evidence review.

Highlights

- Large opportunity (and need) for private household investment in energy retrofit
- Additionality, leverage and overall scale all contribute to policy effectiveness
- Financial incentives: loans offer more leverage but are less attractive than grants
- Effective policy requires a holistic ‘push-pull’ approach across demand and supply
- Tension between efficiency and effectiveness in policy promoting private investment

Keywords

Policy; energy efficiency; retrofit; housing; evidence review

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Abstract = 249, Manuscript text = 7,390 References = 2,109

List of abbreviations and key concepts

- Additionality: the additionality of a retrofit programme is the proportion of the retrofit measures, energy savings or overall retrofit investment that occur as a result of the programme and that would not have occurred in the programme's absence.
- BBNP: Better Buildings Neighborhood Program, a USA policy programme incorporating over forty different state or local energy retrofit schemes.
- EA: Energy Assessment. An assessment of a property's current energy performance and/or potential for energy retrofit, carried out by a qualified professional.
- EPC: Energy Performance Certificate
- ESO: Energy Supplier Obligation, a government policy that obliges energy suppliers that conform to certain criteria e.g. number of customers, to instigate energy efficiency measures, normally extending outside their organisation.
- Free-riding: beneficiaries of a retrofit programme that would have carried out the subsidised retrofit in the absence of the programme are considered to be free-riding.
- GD: Green Deal. A UK policy programme running from 2012-2015 that involved on-bill financing for energy retrofit.
- KfW: Kreditanstalt für Wiederaufbau, a German government-owned development bank that helps to facilitate retrofit incentive programmes
- Leverage: the relative ratio of private to public funds deployed as the result of a policy programme
- Non-participant spillover: retrofit that is carried out by households that did not participate in a retrofit programme, but which was stimulated by the retrofit programme's impact on the overall retrofit market structure i.e. expansion of retrofit suppliers, and reduction in cost of retrofit supply.
- OP: obligated parties. An energy supplier or other party that is obligated as part of an Energy Supplier Obligation (ESO) obligations as part of an Energy Supplier Obligation (ESO)
- Participant spillover: retrofit that is carried out by the participant in a retrofit programme, that is additional and at a later date to that which was facilitated by their participation in the retrofit programme
- RMI: Repair, Maintenance and Improvement. General, amenity, non-energy home improvement or renovation.
- SME: Small and Medium-sized Enterprises

1. Introduction

Given its potential to mitigate the impacts of climate change, alleviate fuel poverty and address a number of other social and economic policy objectives there is a clear case for the public funding of home energy retrofit [1]. Home energy retrofit can involve improvement in a building's fabric to reduce heat loss e.g. through insulation of walls, the addition of double or triple glazing etc., or improvement in the efficiency of an energy using technology e.g. a gas or oil boiler. The public policy rationale is complemented by a private household rationale, given the benefits that accrue solely to the homeowner, such as the potential for a warmer, more comfortable home, lower energy bills and other private benefits.

Retrofit policy and activity span different types of households, including those that rent privately, those in some form of social housing and those that are owner-occupiers. Owner-occupation is often the largest tenure type in the overall housing stock – the majority of homes in each EU member state are owner occupied [2] – and presents a distinctive challenge for retrofit policy. A large proportion of owner-occupiers are deemed 'able to pay': to contribute to the cost of retrofit. This paper reports research focused on the potential contribution to overall retrofit of able-to-pay owner-occupiers.

A wide variety of policy options can be used to encourage retrofit investment by owner-occupiers. Historically, policy efforts in many countries have tended to favour a liberal economic approach, involving market mechanisms and information provision, rather than regulatory standards that enforce change [3,4]. While market-based policies have helped to deliver considerable increases in energy retrofit in many countries in recent years, they have typically been implemented on a cost-effective-first basis [5], and as a result the most economically viable retrofit has been prioritised – progressively diminishing the economics of future retrofit opportunities [6]; even so, there are often considerable remaining opportunities [7].

In some jurisdictions, there are specific targets for the level of retrofit installation, while other policy contexts seek improved levels without a defined target. In Scotland, for example, the recently launched Energy Efficient Scotland route map [8] sets out an ambition for a potential £10 billion investment in energy efficiency in buildings over its 20-year lifetime. Although precise levels of investment are uncertain, available public funding is likely to be well below this figure; less than £1 billion is available over the next 5 years [8]. There is, therefore, a looming investment gap between available public funds and the anticipated overall investment needed – a gap that could be partly met by owner-occupiers, which make up over half (58%) of the Scottish housing stock [9]. In this context, retrofit policy can be assessed in terms of how effectively it addresses overall objectives for energy/carbon savings, fuel poverty alleviation and so on, but also in terms of how efficiently it *leverages* private investment, and the extent to which it supports *additional* retrofit beyond that which would have happened irrespectively.

In retrofit studies, the term 'leverage' refers to mobilising private funding using public funds [10]. The principle of public funds being used to leverage additional private investment is relevant to other areas of finance, particularly broader climate finance, but also international development financing [10,11]. The gap between official targets for retrofit and available public funds can mean that there is an expectation (implicit or explicit) for private investment, and, although not routinely measured, the degree of leverage initiated by publically funded programmes can be used as a means of assessing the programme's effectiveness [12,13].

This paper focuses on policy interventions that seek to facilitate a contribution from private households to home energy retrofit, and reviews evidence of the effectiveness and efficiency of different types of policy instruments in this area. We report the findings of a systematic review of the evidence on the relationship between private and public contributions, and how policy can be designed to more effectively enhance private investment.

We first outline the particular approach to systematic evidence review adopted here. We then assess historic evidence of relative private and public investment levels and how these should be quantified. From this base, the study considers a mix of evidence on the effectiveness of different policy instruments, including formal evaluations of policy and more qualitative and 'opinion-based' studies involving expert interviews and focus groups. Finally, we consider the implications of the review for future retrofit policy, and how policy effectiveness in this critical area can be enhanced.

2. Design and Methods

From a systematic evidence review perspective, our study addressed a relatively broad policy question: 'How can public policy more effectively encourage private, 'able to pay' households to invest in energy efficient retrofit?' In order to address this broad question, our research design involved an adapted approach to systematic evidence review spanning multiple relevant factors. This included evidence on both *how effective and how efficient* different approaches to policy have been in attracting private investment (in terms of additionality and leverage), but also the reasons *why policy may or may not function effectively and efficiently*, in terms of demand- and supply-side factors, and overall policy dynamics.

2.1. Stage 1: scoping literature review

An initial scoping literature review was undertaken to identify the key themes in the evidence base and provide structure to the process of evidence synthesis. We adopted a 'realist' approach [14–16] entailing the identification of 'candidate' themes which could be adapted during the full review, if it became clear that it was more appropriate to address a modified theme with the gathered evidence.

The ultimate themes used to structure the evidence review were:

1. Private household investment and public policy
2. Demand-side: policies aimed at households
3. Supply-side: policies aimed at actors involved with the delivery of retrofit
4. Overall policy mix dynamics

2.2. Stage 2: Full systematic evidence review

Evidence collection, analysis and report drafting took place over 6 months. Our approach to systematic evidence gathering built on that used by the UK Energy Research Centre's Technology and Policy Assessment function [17–19], but also drew on other similar approaches [20–22].

With a few exceptions, we focussed on academic, peer-reviewed literature from a defined geography (Europe and North America) and history (2008-2017), partly due to the pragmatic necessity of bounding the evidence base, while also ensuring maximum relevance.

Clearly, evidence from a particular case in a particular context is not automatically transferable to other contexts, but a systematic collection of evidence may nevertheless offer some indicative lessons on policy effectiveness. The transferability or otherwise of international case evidence is a key issue in the policy transfer literature (e.g. [23–25]). We discuss this issue in the context of our evidence base in Section 4.

As well as peer-reviewed academic evidence, there is considerable non-academic, 'grey' literature of relevance to our review. Gathering this non-academic evidence was partly addressed by the next stage of the method (stage 3) but a lack of comprehensive analysis of the grey literature base, is a limitation of the study. Our focus on mostly academic literature – a common approach in systematic evidence reviews (e.g. [26]) was ultimately deemed necessary as a means of bounding the evidence gathering stage. We gathered evidence from widely used *Scopus* and *Web of Science* academic search engines, using the following search terms:

Table 1: Evidence review search terms

Policy related terms	**Retrofit related terms**	**Policy effectiveness related terms**
Policy	Energy	Effective

Energy	Efficiency	Effectiveness
Effective	Retrofit	Evaluation
Program(me)	Private	Assessment
	Investment	
	Household	

This search phase generated almost 1000 ‘in-scope’ academic papers. The titles and abstracts of these papers were reviewed and ranked in terms of their relevance to the review question. Ultimately, 81 articles were given a full reading. The gathered evidence was a mix of original empirical studies on the impact of policy programmes, alongside more ‘advocacy’ based findings arising from expert interviews and focus groups.

Articles that received a full reading were coded using the following criteria:

- Geographic region: to what geographic context / policy jurisdiction does the evidence apply?
- Policy option: what specific form(s) of policy intervention were under investigation?
- Time period: year of publication and period of implementation or assessment of the policy programme

2.3. Stage 3: Expert Group peer-review

Policy-relevant applied research often lacks the “accumulation of knowledge that characterizes organized areas of scientific investigation” [27]. In place, an expert peer-review process can be used to assess and verify contextual evidence. Our draft evidence review was subject to peer review from several project advisors and topic experts, representing a range of senior academic, policy and stakeholder perspectives. Due to the breadth of the topic, it was not possible to present an exhaustive survey of evidence on each of the themes. The expert peer review process allowed critical review of the initial evidence synthesis, but also directed the analysis toward additional relevant evidence, academic and non-academic.

Feedback from the draft review report highlighted additional evidence, including ‘grey’, non-academic sources, and these were added to the evidence base to more comprehensively address the review question. Following peer review, a further three months was spent considering additional evidence. The final review spanned 58 sources: 50 peer-reviewed academic papers, 1 conference paper, and 7 ‘grey’ literature documents.

3. Results

3.1. Private and public contributions to the cost of retrofit

The first section of the review addresses how policy effectiveness for private household investment in retrofit should be quantitatively assessed. It first considers evidence on additionality: the *effectiveness* of retrofit policy, in terms of the extent that it facilitates additional retrofit or whether it supports retrofit that would have taken place irrespectively. It then addresses the extent to which policy leverages private household investment i.e. policy *efficiency*.

3.1.1. Additionality: does public policy encourage 'additional' private investment in retrofit?

The 'additionality' of a specific retrofit policy programme can be expressed as a percentage of the total number of retrofit measures, estimated energy saved or retrofit investment spend that *would not* have occurred in the absence of the programme. The measures, energy savings or retrofit investment that *would* have otherwise occurred can be termed the 'free-riding' component.

In the USA the term free-riding is not normally used; instead, efficiency programmes distinguish between 'gross' and 'net' energy savings using the Net-to-Gross (NTG) ratio [28]. There are different approaches to estimating NTG, reflecting the inclusion or exclusion of 'participant' and 'non-participant' spillovers. Participant spillovers entail retrofit measures implemented by participants in the programme, but for measures which do not receive any direct public subsidy. Non-participant spillover occurs when a policy programme is assessed as having changed the wider market structure, in a way that increased overall retrofit uptake [29]. These direct and indirect effects can be summarised in terms of energy savings:

Net Savings = Gross Savings - Free Rider Based Savings + Participant Spillovers + Non-Participant Spillovers

Additionality and spillovers are difficult to estimate, and the shortcomings of assessment methods are widely accepted in additionality estimation research [29–31]. Estimation is often carried out via self-report surveys, although econometric methods such as logic/ranking/discrete choice modelling can be used. Econometric approaches are generally considered preferable, but are more costly and rely on the availability of appropriate data [29].

The introduction of any policy instrument (financial incentive, information-based, regulatory etc.) will likely result in retrofit that is part additional and part not. It will also result in positive spillovers not directly supported by the programme. The evidence on additionality reported here relates only to financial incentives that cover the direct cost of retrofit, rather than wider retrofit related policies.

Table 2 summarises the additionality and NTG estimates included in this review. The Table indicates that additionality tends to be lower for retrofit that entails the 'replacement' of existing building components i.e. heating system technologies and building fabric components such as doors and windows. In Italy, Alberini et al (2014) found almost 100% free-riding on a scheme that offered subsidies for replacement boilers, while a similar scheme for replacement windows offered 30-40% additionality. In France, Nauleau (2014) found higher additionality with respect to insulation (walls, roofs etc.): 23-58%, than for windows: 15-39%. More free-riding should also be expected when a subsidy is applied to products that go through a regular replacement cycle, such as boilers, as opposed to ones that are new or 'supplementary' such as new insulation. The non-academic 'grey' literature on additionality (which tends to focus on the USA) also highlights different levels of additionality for different types of measure [28,31].

Table 2: Additionality estimates from different retrofit schemes

Source	**Policy instrument**	**Context**	**Retrofit activity**	**Method of calculation**	**Additionality* or net-to-gross ratio**
Alberini et al., 2014	Tax incentive (income)	Italy, 2007-2009	Heating system replacement	Multi-year, multi region consumer survey	0% additionality

Alberini et al., 2014 [32]	Tax incentive (income)	Italy, 2007-2009	Door or window replacement	Multi-year, multi region consumer survey	30-40% additionality
Nauleau, 2014	Tax incentive (income)	France, 2005-2011	Windows/Glazed surfaces	Household survey conducted before and during period of policy	15-39% additionality
Nauleau, 2014, [33]	Tax incentive (income)	France, 2005-2011	Opaque surface insulation	Household survey conducted before and during period of policy	23-58% additionality
Bundgaard et al. 2013[34]	Subsidies and/or advice	Denmark, 2006-2011	Various measures	Phone survey on likelihood to retrofit without grant	20% additionality
Bard et al. 2011 [35]	Grant	Maine, USA	Various measures	Survey on likelihood to retrofit without grant	86% additionality
USDOE, 2015 [36]	BBNP in the USA – different policy instruments	USA	Various measures	Self-report survey	94% Net to Gross (NTG) ratio
Skumatz et al. 2010 [31]	USA – different policy instruments	USA	'Home retrofits'	Different methods: ex-ante and ex-post, survey based methods and econometric modelling.	50% - 100% NTG ratio

*Additionality in these estimates is typically measured with respect to energy savings.

Participant spillover is thought to be of lesser impact than non-participant spillover. In a review of energy efficiency programme evaluations in the USA, participant spillover was normally estimated at less than 5%, while non-participant spillover estimates ranged from 5% to 100% [29]. The Energy Trust in the USA currently apply a 7% value for non-participant spillover for programmes relating to existing buildings.

3.1.2. Leverage: relative private and public investment

As with additionality, leverage may be defined in different ways in different analyses, and can be estimated in relation to any policy instrument that uses public funds to stimulate private investment. However, it is usually defined solely with respect to financial incentives (potentially from multiple public sources, including central government, energy supplier obligations, local authorities, etc.), with the *leverage ratio* defined as the ratio of private-to-public funds deployed. Table 3 contains leverage ratio estimates included in this evidence review.

Table 3: Leverage: examples of public-to-private funding ratios*

Scheme	Leverage (private funding as % of public funding)	Source
UK, ESO - 2002-2005	79%	[13]
UK, ESO - 2005-2008	55%	
France, ESO and Tax credits – 2006 - 2009	37%	
Denmark, ESO - 2011	240%	
USA, HESP grants scheme – 2010-2011	240%	[37]
USA, PACE loan scheme – 2011-2012	320%	
Germany, KfW loan scheme – pre 2011	400%	[38]

** Some estimates specifically include only additional retrofit, while others do not refer to levels of additionality. Not all leverage studies here offer indirect cost estimates and the decision to only include direct costs in the review was made to provide directly comparable figures. The leverage calculations involve only direct costs and do not include public funds used to cover the development, administration or marketing of retrofit policy programmes.*

UK data: includes only data for the 'able to pay' population in the programme. Includes third party contributions i.e. housing association, local authority, in overall public funds. Data relates to private funding contributions that are additional, assuming 80% programme additionality.

France data: data applies to whole population, with no focus on priority or able to pay populations. Includes energy supplier obligations and tax credit programme contributions to overall public funds. Programme assumes 100% additionality.

Denmark data: data applies to whole population, with no focus on priority or able to pay populations. The estimates assume that 10% of the retrofit measures supported by the programme were additional.

USA data: data applies to whole population, with no focus on priority or able to pay populations. Assumed 86% additionality.

Germany data: data applies to whole population, with no focus on priority or able to pay populations. Additionality estimates unknown.

The wide variation in leverage ratios in Table 3 to some extent reflects whether the scheme has a focus on certain priority social groups (e.g. low income or elderly households) which are less able to make a private contribution to the cost of retrofit. This is the case, for example, with respect to UK schemes, where a significant portion of public funds are ring-fenced for allocation to vulnerable groups; by contrast, the equivalent German loan scheme has a much lower proportion of ring-fenced funds [1]. Despite these limitations, the findings provide an example of the relative contributions to the cost of retrofit that can be made by private and public sources. Other possible reasons for the wide variation in leverage ratios in different countries are discussed later in the paper.

3.2. Demand-side support: retrofit policies aimed at households

3.2.1. Financial incentives

A range of financial incentives are used to stimulate household energy retrofit activity, often in combination, so that assessing the effectiveness of any one type of incentive can be problematic. *Grants* are probably the most widespread form of support internationally [39,40]– their simplicity is a key factor in their appeal [39]. *Tax incentives* are another popular form of incentive, although they have less 'reach', as not all households pay all taxes, and the saliency of the tax to households is an important factor in their effectiveness [41]. Unlike grants, tax incentives are ordinarily received after the retrofit investment has been made, and so do not address the barrier of a prohibitive upfront investment cost [42]. Grants or tax incentives linked to energy savings have been found to be less appealing to households than a fixed incentive [43].

Loans have a range of design features that can be adjusted to make them more attractive e.g. lower interest rates or different repayment terms [44]. Policy options here include the use of public funds to 'buy-down' the commercial interest rates, or loan guarantees or loan loss reserves to cover some of the lender's risk, with the intention of reducing interest rates. Several studies suggest that loans are less attractive to households than 'non-repayment' incentives such as grants or tax-incentives; although non-repayment incentives tend to generate lower leverage ratios than loans [39,45,46].

A common means of administering financial incentives is via the use of *energy supplier obligations* (ESOs), under which registered suppliers are required to provide support to households for energy retrofit measures. An important issue here is that ESOs often focus on the most cost-effective retrofit measures [47–49], leading to the pursuit of short-term, inexpensive measures, rather than those with a higher upfront cost but a longer lasting impact [50,51].

Rohde et al. [13] found that leverage ratios in Danish ESOs were much higher than in UK and French equivalents, as they offer support at the time of the regular maintenance cycle; the authors add, however, that this has negative implications for the scheme's additionality, as "the higher the leverage factor, the lower the additionality" (p. 139). This highlights a tension or trade-off between retrofit policy efficiency (in terms of maximising the leverage of public funds) and overall effectiveness (in terms of maximising the additionality of public incentives). Obligated parties under a supplier obligation will seek to meet their obligations with minimum expenditure and thus focus on activities that are close to happening anyway in order to maximise private household contribution; they seek high leverage but are unconcerned with additionality.

3.2.2. Information-based policy options: persuading households to retrofit

A popular policy mechanism for offering households information on retrofit and its benefits is *Energy Performance Certificates* (EPCs). Despite their widespread use, however, evidence on the effectiveness of EPCs is mixed. For example, a large sample online survey (n=700) on the usefulness of EPCs in Denmark suggested that home owners do not perceive themselves as lacking knowledge on the energy efficiency of their home, or how to improve it [52]. Although the information in Danish EPCs was considered reliable, it was also too general and superficial to greatly influence homeowners' energy retrofit practices; Christensen et al. [52] concluded that the usability of the recommendations should be improved by including DIY recommendations or guidance on finding qualified tradespersons. Murphy et al. [37, p.466] cite research by Gram-Hanssen et al. [53] that also highlights the weaknesses of the EPC as a stand-alone tool, adding that it ''will only be effective if the prospective informees are sufficiently interested to want to help themselves to the packages on offer''.

Energy assessments are distinct from EPCs on account of their face-to-face (advisor to householder) element; even so, evidence of their effectiveness in promoting retrofit investment is again mixed.

For example, Murphy's analysis of energy assessments in the Netherlands [54] compared the level of retrofit activity of a group that had an energy assessment with one that did not; no demonstrable impact was found: the control group carried out as many measures as the assessment group.

The effectiveness of energy assessments for German households was analysed by Frondel and Vance [55]. They found some increase in energy retrofit after an assessment, but also, a wide diversity in how homeowners responded to assessments. The effect was not always positive: information sometimes led to households developing a more negative view of retrofit, if the assessed costs and benefits were less favourable than anticipated.

In their review of household energy investment decision making decisions, Kastner and Stern [27]found face-to-face assessments had some positive influence on investment, but also highlighted the methodological difficulties, arguing that the value of energy assessments and consulting would be more accurately measured indirectly, via long-term observation, rather than by self-reporting by households. Kastner and Stern [27] also highlighted other studies in which the effectiveness of an energy assessment was seen to depend on the perceived credibility of the assessor.

3.2.3. Demand-side policy package design

Several sources make reference to the need for both 'carrots and sticks' in an overall demand-side policy package design [40,41,56]. Killip [57] highlights the 'market transformation' approach used effectively to promote condensing boilers in the UK, with financial incentives being followed, over time, by voluntary standards, and then mandatory ones. Such a ramping-up of minimum standards via regulations is routinely applied to new technologies, but is more problematic and less commonly seen in relation to building fabric. Killip [57] also suggests that voluntary standards should not only precede compulsory standards, but also be raised when compulsory standards are introduced, so as to promote further innovation. Regulations, although seen as necessary to improve standards, may lead to additional training and accreditation needs on the supply-side.

Different retrofit policy instruments have the potential to reinforce or counteract one another, with their combined effectiveness potentially greater – or less – than the sum of their parts. Rosenow et al. [40] concluded that information measures, energy labelling schemes and standards can reinforce the effectiveness of *all* other instruments, while fiscal measures such as an energy or carbon tax can also act to reinforce other instruments (but are also seen as having greater political challenges). In a further paper Rosenow et al. [56] note that a single household is likely to be receptive to different retrofit support incentives at different times, and so a comprehensive policy package across different stages is required.

Rohde et al. [13] highlight that leverage of private investment with public funds is much larger in Danish ESOs than in the UK and French equivalents due to the Danish scheme encouraging support at a renewal point (or 'trigger point') in the regular maintenance cycle. Weiss et al. [51] highlight a widespread observation: that the point of general home renovation is "the most opportune moment to make relatively inexpensive energy efficiency improvements". Galvin [58], Bundgaard et al. [34] and Weiss et al. [51] argue that if retrofit takes place alongside general renovation its overall economic viability can be improved. Weiss et al. highlight the transfer of ownership as a potential 'trigger point', while Caputo and Pasetti [59] identify the repair or replacement of a failed or obsolete component, such as a broken heating system, as an appropriate opportunity. The potential to link energy retrofit with general refurbishment and / or routine maintenance was also made in multiple UK-based studies (e.g. [60–62].

Some experts support the idea of a 'whole house' approach to retrofit, given its promise to maximise overall cost efficiency and minimise householder hassle and disruption [63,64]. However, Fawcett [65] highlighted that many households find a whole house approach impractical, and are likely to be more attracted to retrofit measures that take place over time, spreading the cost and disruption. With such phased retrofit, it is important to consider the order and potential combinations of measures; 'Low Carbon Retrofit Plans', including all the different specific measures appropriate for a property, are a suggested means for organising retrofit over time and ensuring cost and energy savings efficiency [65].

3.3. Supply-side: retrofit policies aimed at actors delivering retrofit

3.3.1. Supply side actors

As part of energy retrofit policy effectiveness, a number of studies highlight the importance of including those involved with supplying general renovations or refurbishment – so called 'repair, maintenance and improvement' (RMI) activities [60,66,67]. The vast majority of retrofit in the UK and USA takes place alongside general renovations [66], and seeing retrofit as a distinct activity artificially decontextualises it for many households. In the UK, expenditure on general RMI has been estimated to be around 20 times greater than on energy related retrofit [57].

The supply of both energy retrofit and more general RMI involves multiple micro-firms which frequently operate in 'temporary multi-firm configurations' [68]. Several studies highlight the risk averse nature of the retrofit supply chains [57,67–70] with low margins instilling conservatism and impeding innovation [68]. Some authors cite a lack of trust in installers among households as prohibiting uptake [39,71], with high quality in retrofit practice seen as an important way to promote 'word of mouth' marketing [69].

3.3.2. Policy and the supply-side

There is some evidence that retrofit supply-side actors are overlooked or marginalised in retrofit policy design[45,67]. In the UK, for example, the expectation has largely been that demand will stimulate supply [4], while in the USA, policy more effectively involved 'push and pull', simultaneously addressing supply and demand actors. Policy in the USA engages with homeowners and supply-side actors using a variety of 'touch points' (points of contact between the household and the those delivering retrofit) and trusted messengers, as a means of boosting the conversion rate – from assessments to installations.

As highlighted earlier, several studies emphasise the value of linking energy retrofit with more general household renovations [51,52,58,60,66]. Owen et al. [67] outline the importance of installers and advisors from the general RMI sector for household decision making about low carbon technologies. Killip [70] estimates that almost half of the total RMI market presents opportunities for integrating energy retrofit measures.

Given the risk averseness of the retrofit and renovation sectors, policy needs to offer incentives and solutions that reflect the installer's business motivations. Gooding and Gul [69] advocate increased dialogue between policy makers and private businesses, in terms of what is realistically deliverable. Gillich et al [4] found that the most effective policy programmes in the USA engaged with supply contractors on an ongoing basis, so that the perceived benefits of participating in a programme outweigh their costs, and compared favourably with a 'business as usual' approach [72].

Workforce training and work inspection are seen as critical factors in several European studies [57,73–76]. Killip [77] highlighted the importance of an intermediary or 'integrator' body as a means of ensuring retrofit projects were effectively implemented. Gillich [4] highlighted the important supplier-householders bridging role of energy advisors in USA retrofit programmes. Such an approach is linked to the *Community Based Social Marketing* (CBSM) approach to retrofit, and the use of multiple 'touch points' in USA policy.

Improved accreditation is another means of building trust in the supply chain [49,69,78]. Training is not just seen as important in terms of the detailed practices of installation, but also in the more general ways it can support 'heightened customer service' [69], and in raising interest in retrofit upgrades among homeowners [4].

Wade et al. [79] highlight the importance of ensuring that supply-side actors are able to preserve their 'hard-earned expert identity'; drawing on Janda and Parag [80], Wade et al. [79] stress that policy needs to consider how these actors can give greater consideration to energy issues. Following Owen et al [67], Wade et al. [81] also highlighted that supply chain actors such as plumbing and building merchants offer a useful point of contact for dispersed supply-side actors.

3.4. The overall policy package: stability, flexibility and simplicity

3.4.1. Policy stability

A repeated theme from the international research on retrofit policy effectiveness was the importance of policy stability [4,39,73,75,82,83]. In the UK, Kern et al. [82] argue that the high 'churn' in retrofit policy in the period 2000-2014 led to increased uncertainty for stakeholders and households, and a rapidly fluctuating policy environment hindered innovation and investment.

The evidence suggests that policy stability is key for supply side actors as well as the demand side. Gooding and Gul [69] report that UK retrofit supply side actors suffered from a pattern of 'boom and bust', and a longer term outlook was needed to make retrofit businesses and careers more attractive, thereby helping to address some of the issues with the low quality of many installations. Gillich et al. [4,72] highlight that contractors were unlikely to change their business models toward more energy efficient installations unless they were given more consistent policy signals about the long term benefits involved. Kempa and Moslener [44] note that a long term strategy has the potential to stimulate innovative practices and cost reductions in retrofit technologies and installations.

Successfully engaging households in retrofit investment requires stable and predictable long term support schemes because refurbishment is often carried out in isolated episodes, one step at a time [51]. In Gooding and Gul's analysis [69], a longer term policy outlook was associated with raised public awareness of the benefits of energy retrofit with a suggested stronger link between home energy performance and house prices. In her analysis of a tax credit policy instrument in France, Nauleau [33] also highlighted the benefits of policy consistency, simplicity and good communications.

Whilst some degree of policy change is inevitable (and desirable, to respond to changing circumstances and opportunities), studies also highlight the importance of having a long term strategy [41]. Kempa and Moslener [44] note that a long term strategy has the potential to give rise to innovative practices and cost reductions.

One important feature of credible, long term policy making is stable funding, such as can be offered through the use of a dedicated fund for retrofit. In Germany, Weiss et al. [51] highlight the potential benefits of a stand-alone energy efficiency fund in helping to ensure the continuation of subsidy programmes and thus improving their saliency and coherence. Gouldson et al.'s [83] model of a 'revolving fund' that is replenished via the receipt of a portion of forecast energy bill savings could help ensure stability, and depoliticise public expenditure.

3.4.2. Policy flexibility

While stable and credible retrofit support is repeatedly mentioned in research, a degree of policy flexibility is also called for – there is no value in policy stability if the overall package is ineffective. Policy flexibility matters both with respect to revising programmes over time, and also devising policy packages that are flexible enough to cater for the different characteristics of different households and regions.

Murphy et al. [63] highlight the benefits of short-term review cycles for retrofit policy targets within long term stability, allowing for improvements and adjustments in policy design. The highly distributed and small scale nature of the retrofit industry may mean that regionally flexible policy implementation is appropriate. Gillich et al. [4] suggest that a significant aspect of the successes of the Better Buildings Neighborhood Program in the USA was its geographic (interstate and intrastate) flexibility. Interviews with supply-side actors suggest that the UK Green Deal may have performed better if it was able to make adaptations over time [69].

Hoicka et al. [43] argue that given different households respond differently to different programme designs, 'one size fits all programmes' should be avoided – instead, policy designers should target sub-sets of the population to achieve the desired outcomes. Such 'market segmentation' approaches are also advocated by others (e.g. [72]), but designing specific policies for specific groups may put pressure on government capacity, as well as being at odds with calls for policy simplicity and consistency; they also risk creating 'post-code lotteries', in terms of eroding universal access to funding support.

3.4.3. Policy simplicity

Curtin et al. [39] highlight several studies that suggest that grant application processes can be off-putting for households, and conclude that simplicity in the application process was a 'key success factor'. A similar observation was made by Weiss et al. [51] with respect to policy successes in Germany, especially for loans at local banks and among households with little previous interest in energy conservation. In an analysis of a broad set of energy efficiency policies in Malaysia, Hor and Rahmat [84] conclude that a tax incentive scheme for residential and commercial buildings received only a small number of applications because of its lengthy and cumbersome approval process.

4. Summary and Discussion

Due to the considerable public goods benefits associated with a more energy efficient housing stock, there is a strong case for public funding to cover much of the cost of home energy retrofitting. The extent of the public contribution is, however, uncertain, and contingent on political priorities and the appeal of retrofit relative to other low carbon transition options. As a result, there is a substantial opportunity (and need) for a private contribution to potential retrofit investment, private investment that will secure private benefit (for example in terms of lower energy costs and improved thermal comfort) alongside the shared public benefits of lower GHG emissions and lower total energy demand. The rationale for our review stemmed from the disparity between required investment in home energy retrofit given increasingly ambitious public policy targets, and available public funds.

In order to understand how policy can effectively encourage private household investment in retrofit, the review first considered evidence on policy efficiency in terms of public investment leverage and additionality. We then reflect the wider dependencies of public policymaking in this area by reviewing evidence on policy effectiveness in terms of demand-side policy interventions, supply-side interventions and overall policy dynamics. Our overall evidence base spanned a mix of quantitative evaluations of policy instruments and qualitative assessments of the design and focus of policy.

Over the course of the review, there was a developing awareness of the need for a broadening of retrofit policy effectiveness beyond more narrowly defined economic and financial efficiency, to also include agency, institutions, and local context. There is a strong case for a broader, holistic approach to evidence gathering, as a pre-requisite for effective and durable policy making in this area. Government support for retrofit is often associated with multiple (and potentially conflicting) policy objectives: climate change policy promotes retrofit as a means of achieving energy savings and reduced carbon emissions, while energy affordability policy promotes retrofit as a means of achieving warmer living conditions and not necessarily saving energy.

Another theme that emerged from the review was a tension between policy efficiency and policy effectiveness, especially as overall policy ambition grows, and policy interventions diffuse through the greater part of all households. These tensions and trade-offs are evident in additionality and leverage assessments. How much *additional* retrofit that policy facilitates is difficult to measure accurately with methods such as ex-post, self-report surveys, subject to well-recognised flaws. Even so, any particular policy programme is unlikely to facilitate entirely additional measures. A wide range of additionality and leverage assessments were encountered in the review. This variety reflects different policy designs: whether interventions rely on loans, grants or tax incentives and whether they apply universally to all households or whether incentives are targeted at particular types of household.

As would be expected, higher levels of leverage are associated with loan programmes compared to non-repayment subsidies such as grants and tax-incentives. Policy instruments with higher private funding contributions are, however, less appealing to households and thus may result in less uptake and reduced overall retrofit implementation. Households are also less likely to adopt incentives that are performance-based rather than fixed, although from the public policy perspective the latter offer more efficient use of public funds. Private investment in retrofit can also arise from direct and indirect spillover effects, although no evidence was identified here on whether different forms of financial incentive facilitate different levels of participant or non-participant spillover.

Clearly, additionality cannot be the sole metric of retrofit policy effectiveness: a scheme could achieve 100% additional retrofit, but result in only minor changes across the housing stock as a whole. Narrow focus on maximising additionality may minimise overall retrofit uptake – and lower additionality tends to be associated with more commonplace, replacement measures. Retrofit policy faces the dilemma of trying to simultaneously maximise additionality, leverage and uptake, and rather than any single metric, policy effectiveness in this area should be considered in relation to multiple factors (Table 4).

Table 4: Factors affecting retrofit investment policy

Factors	Description
Available public funding	How much public funding is available?
Level of public subsidy	What % of total retrofit investment is covered?
Take-up of subsidy	What % of available public funds are used?
Additionality	What % of retrofit projects subsidised are additional?
Leverage	What is the private to public investment ratio?
Participant spillover	Does the public subsidy result in the subsidised household investing in more retrofit at a later date?
Non-participant spillover	Does the public subsidy scheme result in a stimulus to the overall retrofit market?

The evidence highlights the importance of trigger points, when households are more willing and able to carry out retrofit, such as episodes of general renovation or when moving house. Policy incentives that are designed around these points will tend to encourage uptake with lower levels of subsidy and so achieve higher leverage than would be achieved otherwise. However, whether such targeted incentives result in greater additionality is a more open question, and would have to be judged on a case-by-case basis.

Regulations mandating minimum energy performance will typically stimulate both additional and non-additional retrofit. Implemented in isolation, regulated standards would not involve a public contribution to the direct cost of retrofit, and therefore leverage ratios would not apply. Often, however, regulations are introduced alongside a financial support mechanism – a 'carrots and sticks' approach – and in such cases regulations are likely to improve the additionality of the financial incentive. Sufficient monitoring and verification of regulations (and their adequate resourcing), should ensure widespread adoption, although evidence suggests that their political acceptability can be more challenging.

Evidence of the effectiveness of information-based policy options such as Energy Performance Certificates and face-to-face energy audits is mixed: although they can have some positive impact, this is likely to be limited. Rather than judged in isolation, EPCs and audits should be viewed as a relevant part of an overall retrofit *policy mix*, not least as a means of structuring minimum energy performance regulation.

Advocacy of 'whole house' retrofit stems from a desire to reduce overall householder costs and disruption, but it remains unusual in practice. A home retrofit that occurs episodically over time may be more realistic, but from an policy effectiveness and efficiency perspective, it invites consideration of whether public financial support is necessary at each episode, and whether higher leverage may be possible if the retrofit occurs at a single point.

Policy that engages with supply side actors offers a means to promote household interest in retrofit specifically, but also across the much wider market for general renovation. Supply side policy can generate additional retrofit activity via an installer recommending a policy measure, such as a low interest loan, or in terms of improved training for installers to help take advantage of retrofit project opportunities alongside general renovation. This can be seen as a spillover from non-retrofit to retrofit. Supply-side actors can be key catalysts for such wider market spillovers.

The review considered evidence from a variety of countries / policy contexts, and while it is important to recognise that evidence from a particular case is not directly applicable to a different context, some lessons can be drawn from our systematic approach to international evidence collection. The success of policy transfer between international contexts depends on a number of factors, for example, the existence of comparable institutions and the resources available for implementation [23]. The degree to which evidence is transferable depends on the context to which it is being transferred.

Nevertheless, the evidence base reviewed here can also be seen as covering a spectrum of more generalizable and more specific / contextual findings. This review does not attempt to comprehensively cover all the evidence on the topic and so in our synthesis a greater number of sources associated with a finding does not necessarily equate to greater transferability relative to other findings. The association of multiple studies with a particular finding, such as the potential value in linking retrofit with general renovation, can, however, help to add weight to findings that might be of relevance in other contexts. Ultimately however, transferability must be judged on a case by case basis.

Some findings may be more generalizable due to the nature of the finding, regardless of the number of associated studies. Certain findings result from more widely applicable mechanisms which may mean they are more transferable. For example, the finding that the level of additionality of a retrofit programme might partly relate to the type of measure that is funded i.e. replacement or supplementary measures, is likely to have wide-ranging applicability (see Table 2). That leverage ratios will be affected by whether the programme is focused on priority social groups is likely to also be a generalizable finding (see Table 3).

By contrast, it is likely that more embedded forms of knowledge, such as on homeowner awareness of the available energy retrofit options will vary by region. For example, the finding that Danish homeowners do not perceive themselves as lacking knowledge on energy efficiency may reflect the particular history of energy citizenship in the Danish context [52].

5. Conclusion

Understanding private household investment in home energy retrofit invites a distinctive approach to systematic evidence review – one able to span the varied economic, social and behavioural factors that influence policy effectiveness in this area, and a mixed quantitative and qualitative evidence base.

The review highlighted the varied metrics that can be used to assess the effectiveness of household retrofit policy. Any policy that seeks to intervene in a large and indeterminate social system needs to be developed with respect to the existing baseline activity and its overall additionality. More specifically, policy that seeks to stimulate private investment using public funds, should also be assessed in terms of its ability to leverage private investment. Both of these concepts – additionality and leverage – help to assess policy effectiveness, but by themselves neither offer a full understanding of effectiveness.

To develop a fuller understanding, this review went beyond international comparative data on additionality and leverage, to consider the range of policy interventions addressing actors, organisations and social contexts, spanning both demand-side (householder) aspects, and those addressing supply-side actors such as installers, retailers and designers. This broadening is important as it draws attention to evidence on often neglected aspects of policy effectiveness in this area. Truly effective retrofit policy making should involve simultaneous attention to these different aspects – despite the tensions and trade-offs involved. Ultimately, an effective policy mix of stability, flexibility and simplicity can promote increased household demand for retrofit and a more responsive supply side.

Like other forms of public policy that seek to change behaviour, retrofit investment policy options span a spectrum of measures from persuasion to coercion. There can be no universal optimal position on this spectrum – governments of different ideological hues will have different orientations in terms of economic distribution and social equity, differences that increasingly affect energy policy more widely. Even in such politically contentious areas a broad based, realist version of systematic review can help promote evidence-based and effective public policy.

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