LOW CARBON LIVING CRC

International best practice on financing models for low carbon / energy efficient buildings

Rapid systematic review of evidence

SP0020p4

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Paul Twomey, Malgorzata Lagisz and Maria Balatbat declare no conflicts of interests.

Peer Review Statement

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The author(s) confirm(s) that this document has been reviewed and approved by the project's steering committee and by its program leader. These reviewers evaluated its:

- originality
- methodology
- rigour
- compliance with ethical guidelines
- conclusions against results
- conformity with the principles of the Australian Code for the Responsible Conduct of Research (NHMRC 2007),

  and provided constructive feedback which was considered and addressed by the author(s).

Abbreviations and Acronyms

AMSTAR 2 – A MeaSurement Tool to Assess systematic Reviews, version 2

RoB – Risk of Bias

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Executive Summary

Background

Financing the upfront costs of energy efficiency and renewable energy projects in buildings can be a significant barrier to the growth of sustainable, low carbon buildings. Despite many studies demonstrating that building energy efficiency is the 'low-hanging fruit' of the carbon abatement cost-curve, these opportunities are often not being taken up, with finance being identified as one of the barriers.

Internationally, a number of alternative finance mechanisms have arisen in an attempt to remedy this problem. These approaches can differ across a number of design features including source of capital, customer interface and repayment channel. They have also operated with varying degrees of success.

Objectives

The objective of this review is to find evidence on international best practices on financing models for energy efficiency investments in buildings. For this reason the preference is given to potentially least biased, highest quality, recent and relevant reviews of evidence from developed countries in similar climate zones to Australia. Notably, since the evidence has to be provided within limited timeframe, we do not aim for the comprehensive review of all available evidence, but for a representative sample via a systematic rapid review.

The commissioned review question fits more within the definition of a scoping/mapping review rather than a classical rapid review. However, given the methodology used to find, screen and assess the studies, a "rapid review" label is also appropriate. Rapid reviews generally use simplified systematic review methodology to accelerate the review process, while still trying to minimise the risk of bias (Tricco et al. 2015).

Data sources

Data sources included Scopus, Web of Science and Google Scholar, followed by snowballing from the included full-text articles and searches within other databases, including grey literature (e.g., government reports, theses).

Study eligibility criteria

We included papers claiming to be peer-reviewed systematic reviews and meta-analyses concerning the review of best financing practices as stated in our objectives. Due to the paucity of relevant studies, we extended our inclusion criteria to include narrative reviews and non-peer-reviewed publications from sources deemed trustworthy.

Study appraisal and synthesis methods

We qualitatively summarised studies that fulfilled our inclusion criteria. The quality and risk of bias of these studies used an adapted version of the 16 questions from the AMSTAR 2 tool.

Results

We included three systematic reviews and nine narrative reviews that fulfilled our inclusion criteria. This included three non-peer reviewed studies due to the paucity of peer-reviewed systematic studies closely relevant to the topic of this rapid review.

Limitations

The search was limited to systematic and narrative reviews on the topic and did not seek primary research on specific financing models. As the search was not fully comprehensive (e.g., specialist databases were not searched), some relevant studies might have been omitted. Only grey literature from established international organizations was included.

Conclusions and implications

Overall, the results of our systematic literature search were disappointing. We found a limited number of secondary studies providing empirically backed, strong statements on best practice in finance models for energy efficiency in buildings. Systematic reviews are largely absent from the peer-reviewed literature. Even in the grey literature the reviews we found were not comprehensive.

Nevertheless, the included papers did contain a number of findings and insights that may assist in guiding best practice for financial mechanisms. These include: taxonomies of mechanisms and key design features; barrier analysis and the manner in which different financial mechanisms can address these barriers; financial mechanism success factors; and considerations on how finance mechanisms can integrate with different business models and government policy environments.

A number of the studies highlighted that no single mechanism will necessarily fit all countries or situations. Different geographic, demographic, political and market environments will affect the suitability of any different mechanism.

The results of the rapid review of literature have indicated the need for further research in this area. This would include a comprehensive survey of the different mechanisms used internationally including quantitative data of mechanism uptake and cross-comparisons across the type of evaluative criteria found in this review.

Registration

The protocol for this review has been archived using Open Science Framework (OSF) at*https://osf.io/796un/.*

Amendments to the protocol

The expansion of the literature search and broadening of the inclusion criteria was done due to the insufficient number of relevant studies located in the original search. This change followed the options provided in the protocol (scaling up). During the data extraction stage, types of financial tools considered and the market targeted, type of barriers and/or outcomes considered were all extracted as a single field named "study topic".

Introduction

Rationale

The limited uptake of cost-saving building energy efficiency measures has become a policy quandary sometimes referred to as the 'energy efficiency gap'. The research literature has identified many barriers and factors that have contributed to this problem, including lack of knowledge of options and benefits, uncertainty of benefits, household and business disruption, and the landlord-tenant 'split incentives' problem.

One particular challenge arises from the fact that benefits from energy efficiency or renewable energy investments typically accumulate over long time periods while requiring high upfront costs. For households and businesses that lack the sufficient internal funds, they may seek to access external finance. This may not always be a simple undertaking. Internationally, a number of funding sources have arisen in order to provide financing for energy efficiency and other low carbon investments. These include governments, banks, mortgage providers, energy utilities and energy service companies, using various financial mechanisms and operating with varying degrees of success.

Given the array of financing options that have been employed internationally, an obvious question arises as to whether evidence has emerged for the best financial models for low carbon, energy efficient and affordable buildings. This may not be an easy task to answer given the contested and often contextual nature as to what is meant by 'best practice'. Additionally, the multiple barriers and challenges with regard to the energy efficiency gap mentioned above, make assessing the success of a mechanism difficult to untangle from other issues.

Nevertheless, it may be useful to attempt identifying relevant, reliable and unbiased secondary studies that have reviewed, preferably in a systematic or meta-analytic manner, the primary research on the various methods of financing energy efficient, low carbon buildings.

Objectives

The main question guiding this rapid review was: what are the international best practices on financing models for energy efficiency and other low carbon investments in buildings?

This question fits more within the definition of a scoping / mapping review rather than a rapid review. However, given the methodology used to find, screen and assess the studies, a "rapid review" label is also appropriate. Rapid reviews generally use simplified systematic review methodology to speed up the review process, while still trying to minimise the risk of bias (Tricco et al. 2015). The term "meta-review" is used to describe a review of other reviews and is also termed "overview" (of systematic reviews) in Cochrane, or "umbrella review" (in medical sciences more generally). A new term "scoping meta-review" was recently proposed for the reviews using high-level evidence provided by systematic reviews in order to map new fields or broad topics (Sarrami-Foroushani et al. 2015).

The secondary objective of this project was to assess the time and resources needed to perform a scoping / rapid meta-review on a topic related to the Built Environment. Thus, information relevant to the review team's structure, review timeline and associated workloads are also included in this report.

Methods

Eligibility criteria

The following study characteristics were used as inclusion criteria for the review:

1. Publication year: studies published in and after 2008 (last 10 years)
2. Publication type: studies published as peer-reviewed articles
3. Publication language: studies published in English
4. Study type: secondary studies claiming to perform systematic review, rapid review, scoping review, systematic map, evidence map, meta-analysis or equivalent (from the family of systematic reviews; Moher et al. 2015)
5. Study topic: the main focus on the study is on summarizing financing models of the programs/policies targeting greater energy efficiency of multi-occupancy residential buildings. By greater energy efficiency we mean energy use reductions and/or lower carbon emissions. In terms of the targets of the financing, the focus is on developers, builders, investors followed by building managers or strata managers
6. Study geographical focus: the study's primary focus should be on developed countries in sub-tropical and temperate climate zones (Canada and USA, Europe, Australia, New Zealand and similar countries)
7. Full text available

Information sources

1. Search engines of Scopus, Web of Science and Google Scholar
2. Snowballing (forward and backward reference screening) from the included studies using Scopus search engine and database

Literature search and study records

Search string used for SCOPUS online database search (search date 14/04/2019):

TITLE-ABS-KEY (("meta-analy" OR "meta analy*" OR "metaanaly*" OR "meta-review*" OR (systematic* W/2 review*) OR (systematic* W/2 map*) OR (evidence W/2 review*) OR (evidence* W/2 map*) OR (scoping W/2 review) OR (rapid W/2 review)) AND ("energy efficiency" OR "sustainable energy" OR "energy sustainability" OR "green energy" OR "renewable energy" OR "renewable electricity" OR "household energy" OR "green power" OR "energy program*" OR "energy behavior*" OR "energy consum*" OR "energy polic*" OR "energy us*" OR "energy initiativ*" OR "energy coneservation") AND (resident* OR house* OR home* OR building* OR apartm* OR unit* OR consumer* OR community* OR user* OR *occupan* OR "home*owner*" OR retrofit* OR renovat* OR improv* OR upgrad* OR insulat* OR solar*) AND (financ* OR loan* OR incentiv* OR repay* OR lease* OR grant* OR "one-bill" OR subsid* OR monetary OR fund* OR "PACE" OR "ESPC" OR "ESCO"))*

[69 records found]

Search string used for Web of Science online database search (search date 14/04/2019):

TS=(("meta-analy" OR "meta analy*" OR "metaanaly*" OR "meta-review*" OR (systematic* NEAR/2 review*) OR (systematic* NEAR/2 map*) OR (evidence NEAR/2 review*) OR (evidence* NEAR/2 map*) OR (scoping NEAR/2 review) OR (rapid NEAR/2 review)) AND ("energy efficiency" OR "sustainable energy" OR "energy sustainability" OR "green energy" OR "renewable energy" OR "renewable electricity" OR "household energy" OR "green power" OR "energy program*" OR "energy behavior*" OR "energy consum*" OR "energy polic*" OR "energy us*" OR "energy initiativ*" OR "energy coneservation") AND (resident* OR house* OR home* OR building* OR apartm* OR unit* OR consumer* OR community* OR user* OR *occupan* OR "home*owner*" OR retrofit* OR renovat* OR improv* OR upgrad* OR insulat* OR solar*) AND (financ* OR loan* OR incentiv* OR repay* OR lease* OR grant* OR "one-bill" OR subsid* OR monetary OR fund* OR "PACE" OR "ESPC" OR "ESCO"))*

Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years

[75 records found]

Records from Scopus and Web of Science electronic databases were exported to Mendeley reference management software. Two reviewers (PT, ML) independently screened de-duplicated records (titles, abstracts, keywords) using Rayyan platform (Ouzzani et al., 2016) to identify relevant studies using a pre-defined decision tree reflecting the eligibility criteria described in the previous section.

Full papers were retrieved for studies deemed potentially relevant. Two reviewers (PT, ML) independently performed screening of full papers using same criteria for the titles and abstracts, resolving any disagreements by discussion and cross-checking the final list of included studies and their coding (i.e. data extraction). Studies deemed suitable for inclusion were then used to perform additional snowballing searches (i.e. forward and backward reference screening, as described above).

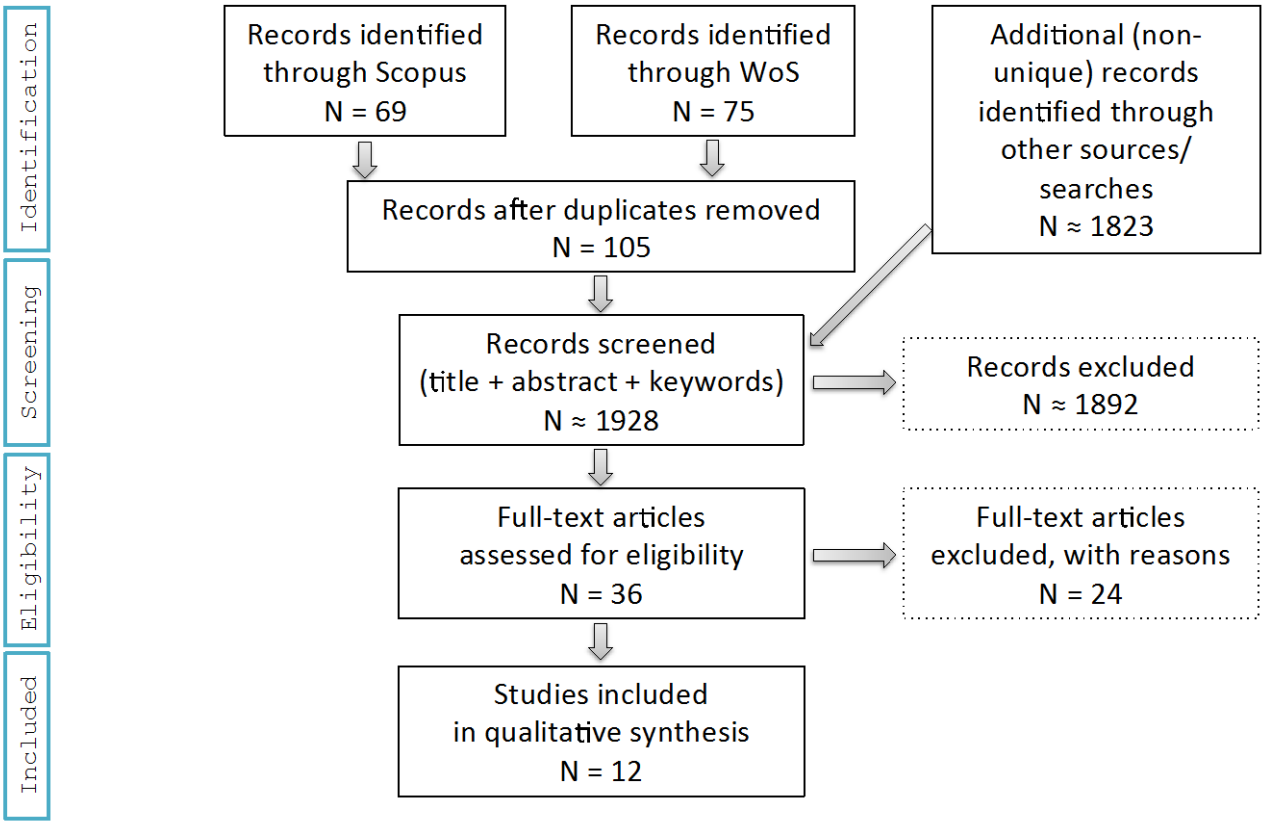
Since the search did not reveal any references that were clearly relevant to the review question, the database search was scaled up. First, relaxing screening criteria to include any papers published within the last 10 years, did not result in any additional inclusions. Second, additional searches in other sources (as outlined in the protocol and listed in Table S1) were performed to locate non-peer reviewed

studies of the following types: MSc and PhD theses, reports by major credible organizations (governmental, research institutes, peak bodies).

In addition, a Google Scholar search was conducted using the following search string: *(building "energy efficiency" financing | loan | subsidy | incentive "systematic review" | "meta analysis" | "evidence review" | "evidence map"| "scoping review" | "rapid review")* **[over 10,000 references found]**. One reviewer (ML) screened the results of this Google Scholar search by looking at the top 100 hits from each year between 2008 and 2018 (1000 hits screened in total and included in Table S1, 18/04/2019).

Finally, ML performed snowballing (i.e. forward and backward reference searches) for the already included reviews and other relevant reviews on the topic (20/04/2019, Scopus database, approx. 546 non-unique references screened, Table S2). The overview of the search and screening process is presented in Figure 1.

Figure 1. PRISMA diagram of the search and screening process



Data items

We extracted the following characteristics for each included study title, author, year of publication, self-claimed study type (e.g., systematic review, meta-analysis), geographic scope (e.g. Australia, Europe, global), types of financial tools considered and the market targeted, type of barriers and/or outcomes considered, key findings, funding and conflict of interests (as declared by the authors). For each study, we have also recorded overall conclusions and any comments of relevance to the rapid review topis.

Table 1 presents the main extracted variables and their values / codes (also used in Tables 2 and 3 in the Results section). Data extraction was performed by one reviewer (PT) and checked by other reviewer (ML). For each study, we have also provided quality assessment scores, risk of bias and overall comments (for details, see the "Risk of bias of individual studies" section below).

Table 1. List of the main study characteristics extracted and coded for the included studies, with relevant values

Study variable	Description
First Author_year	Key (ID) of the article is created by concatenating the last name of the first author and the year published
Reference	Full publication reference information, including title of the article
Study type	Whether the article is peer-reviewed (from and academic journal) or not (e.g. report). Also, recording self-claimed or inferred type of the review (e.g. systematic, meta-analysis, narrative review).
Main topic	Main topic addressed in the article
Geographic scope	Whether the study focuses on a particular geographic region or country type (e.g. developed) or has global focus.
Study conclusions	Conclusions and recommendation of the article, relevant to this rapid review
Comments	Any comments on the study limitations or relevance to this rapid review
Study funding	Funding sources declared in the article
Conflict of interests	Conflicts of interests declared in the article

Outcomes and prioritisation

Not applicable, due to the scoping nature of this review and focus on secondary studies only.

Risk of bias in individual studies

A formal quality assessment of the studies included in this rapid review was performed using the AMSTAR 2 checklist (Shea et al. 2017). Table S4 presents the 16 questions used for this assessment process, with codes and explanations. The assessment was performed by one reviewer (ML).

Data Synthesis

No quantitative assessment was performed due to the heterogeneity and the small number of included studies. A qualitative summary is provided in the form of tables and a narrative description of the patterns and gaps observed in the secondary literature that was reviewed.

Meta-bias(es)

Not applicable, due to the scoping nature of this review and focus on secondary studies only.

Results

The final study list included twelve studies that fulfilled our inclusion criteria (see Table 2). The results included three systematic reviews and nine narrative reviews. Including 3 non-peer-reviewed documents. The three non-peer reviewed studies were included due to the paucity of peer-reviewed systematic studies (from the systematic review family) closely relevant to the topic of this rapid review.

Overview of the included studies

The twelve studies were published between 2010 and 2019, but most (ten) were published in the last four years. Five of the papers could be described as mostly or entirely focused on finance mechanisms, whereas the other seven had finance mechanism as a component of the paper, usually along with analysis of a wider set of energy efficiency policies. All the papers were primarily focused on energy efficiency retrofit, however many of the mechanisms discussed were inclusive of other low carbon investments. The geographical scope was mostly international, with a few review focusing on UK, US, Australia, Spain and Malaysia.

Descriptions of selected conclusions from the twelve studies are contained in Table 3.

Overall, the results of our systematic literature search were disappointing. We found a limited number of secondary studies providing empirically backed, strong statements on best practice in finance models for energy efficiency in buildings. Systematic reviews are largely absent from the peer-reviewed literature. Even in the grey literature the reviews we found were not comprehensive. The most relevant study is Brown_2019. It is also the most recent study. The paper entirely focuses on classifying and describing finance mechanisms for building retrofit and also provides three key success factors that may contribute towards best practice.

Nevertheless, while the results were disappointing, the included papers did contain a number of findings and insights that may assist in guiding best practice for financial mechanisms. They may also help direct further research in this area.

Taxonomies of finance mechanisms

A number of the studies included taxonomies of the different types of finance mechanisms that have been used internationally (Bertone_2016; Brown_2015; Shan_2017; UNECE_2015). One representative taxonomy used six broad categories of financial mechanisms (Brown_2019).

• *Public loan / credit enhancement* - where government provides low-interest rate loans or credit enhancements to private capital loans.

• *On-bill finance* - where funding is provided by a utility or third party with repayments operating through the utility bill.

• *Property Assessed Clean Energy (PACE)* - a USA scheme where municipalities provide funding with repayments through the property tax bill. Australia has a similar scheme called the Environmental Upgrade Agreement.

• *Green mortgage* – where funding is provided by a mortgage provider and repaid through mortgage repayments.

• *Energy service agreements (ESA)* – where building occupants contract for specific guaranteed energy services to an Energy Service Company (ESCO) who themselves finance and implement any energy efficiency upgrades.

• *Community financing* – a 'cooperative' style arrangement where loans are provided from equity capital typically raised from citizens of a local geographic area.

In order to further understand these mechanisms, the same study compared the mechanisms across six design features: capital source, the type of financial instrument, the customer interface, the project performance requirements, the type of loan security and underwriting, the means of repayment and overall customer experience. Table 4, based on Brown_2019, summarizes the above six types of finance mechanisms.

Barrier analysis and coping strategies

A number of the papers analysed finance and other retrofit policy challenges in terms of identifying market and other system barriers. (Bertone_2016; Brown_2015; Gooding_2016, James_2012; Sweatman_2010; UNECE 2015). Policies and strategies can then be framed in terms of how well they address these problems. Finance barriers identified included high upfront costs, long payback periods and owner-tenant split incentives. All the finance mechanisms addressed the first two barriers to varying degrees. On-bill and PACE financing were noted to be particularly useful for addressing the split incentive problem (Sweatman_2010).

Factors related to successful uptake

Some of the factors that may facilitate the successful uptake of energy efficiency measures mentioned in the studies included:

• *Simplicity and ease in customer experience* (Brown_2015; Sweatman_2010; UNECE_2015). A simple process for accessing finance and/or energy services is likely to be attractive, particularly to households. The success of the PACE scheme in the US and Germany's state bank (KfW) loan scheme (CBRP) has been attributed, in part, to the simplicity of the customer interface in attaining the finance (Brown_2015).

• *Finance as part of an integrated business model* (Sweatman_2010; UNECE_2015). Simplicity and standardization benefits also extend to other parts of the value chain. This is an advantage of ESCO services which can integrate financial and technical risks. They can help mediate conflicts of interests between consumers, service companies and financiers.

• *Appealing to broader sources of value* (Brown_2015, James_2012). Households seeking finance for energy efficiency upgrades may also be co-motivated by other sources of household value such as increasing the thermal comfort level, repairing a broken heater or aesthetic considerations. Therefore, a finance mechanism that potentially excludes or lock-outs these sources of value (for example, by including an energy bill neutrality condition) may undermine the uptake of retrofit upgrades. An energy-bill neutrality condition was part of the UK Green Deal on-bill financing scheme and may have been a factor in its failure (Brown_2015).

• *Reducing the cost of capital* (Brown_2015). Not surprisingly, a high cost of capital should be expected to deter households, particularly those with the larger financing requirements of deep, whole-house retrofits. One way to lower the cost of capital is via the direct provision of finance by state banks (such as Germany's kfW) or through government credit enhancements to private capital (such as guarantee funds). With private capital mechanisms only, another means of lowering the cost of capital may be through the securitization of small retrofit loans that could open up capital from large institutional investors such as superannuation funds. However, this would require a depth of market and standardization of project performance protocols that is not widespread at present, aside from the PACE scheme and ESA's in the commercial and industrial sectors (Brown_2015).

Other lessons

A selection of other lessons or insights from the included studies included:

• *Local context - no single measure fits all countries or situations*. A number of the studies highlighted that no single mechanism will necessarily fit all countries or situations. Different geographic, demographic, political and market environments will affect the suitability of any different mechanism. (Bertone_2016; Brown_2015; Curtin_2017; UNECE_2015).

• *Linking finance into a broader set of retrofit enhancing strategies*. One study showed how finance fits into a wide set of interacting issues of the retrofit industry in order to outline a roadmap to improving the speed of retrofitting in Australian public buildings (Bertone_2016).

• *Attributes of 'best policy practice'*. The meaning of the expression 'best practice' in any given study is not always clear. With respect to energy efficiency policies, one study set out four criteria that could be considered (UNECE_2015): (i) significant outcomes, including energy demand reductions (ii) complementarity with other efforts (iii) political alignment and palatability, and (iv) marketability.

Risk of bias in individual studies

Table S5 presents results of quality assessment of the three systematic reviews included in this rapid review (Curtin_2017; Hesselink_2019, Shan_2017). These systematic reviews have several similar shortcomings, including lack of a protocol, not disclosing how many reviewers participated in screening the primary literature and coding data for the systematic review, and the lack of quality assessment of primary studies. Overall, the three systematic reviews included in our rapid review were deemed to have high level of potential risk of bias.

Overview of the excluded studies

Table S3 lists the studies excluded from this review after full-text screening, alongside the reasons for exclusion. Most of these studies were excluded for having limited discussion of financial models, with the content typically focusing instead on barriers to energy efficiency investment or covering energy efficiency incentive policies.

Review Limitations

The search was limited to systematic and narrative reviews on the topic and did not seek primary research on specific financing models. Since the search was not fully comprehensive (e.g., specialist databases were not searched), some relevant studies might have been omitted. Only grey literature from established international organizations was included, other grey literature (e.g., theses, reports) could potentially yield additional insights.

Summary and conclusions

Around the world, achieving greater energy efficiency in buildings continues to be one of the most cost effective yet unused sources of value for countries seeking a low carbon future. Among the many barriers that have been identified in impeding this progress are those related to accessing finance for energy efficiency investments. Various finance mechanisms have arisen in order to alleviate this problem.

This review has sought to find relevant secondary studies, preferably systematic or meta-analytic, on best practice for financing energy efficient, low carbon buildings.

A main finding of this review is that systematic studies of finance mechanisms for energy efficiency investment in buildings are largely absent from the peer-reviewed literature. Even in the grey literature we found relatively few comprehensive reviews.

Nevertheless, the included papers did contain a number of findings that may assist on matters of best practice for financial mechanisms. These included taxonomies of mechanisms and key design features, barrier analysis, financial mechanism success factors, and considerations on how finance mechanisms can integrate with different business models and government policy environments.

The results have highlighted the need for further research in this area. One such research study could include a comprehensive survey of the different mechanisms used internationally, including quantitative data of uptake and cross-comparisons across the types of evaluative criteria mentioned in this review.

Table 2. List and the main characteristics of the included studies

First Author_year	Reference	Study type	Main topic	Geographic. focus	Study funding, Conflict of interests
Bertone_2016	Bertone, E. O. Sahin, R. A. Stewart, P. Zou, M. Alam, E. Blair (2016) State-of-the-art review revealing a roadmap for public building water and energy efficiency retrofit projects, Renewable & Sustainable Energy Reviews - Volume 75, Issue 0, pp. 534-547	Peer-reviewed. Narrative review	Barriers and best international practices for retrofitting public buildings	International with a focus on Australia	Sustainable Built Environment National Research Centre (SBEnrc), Australia
Brown_2015	Brown, M. (2015) Innovative energy-efficiency policies: an international review, WIREs Energy Environ, Volume 4, pp.1–25	Peer-reviewed. Narrative review	Policies for energy efficiency improvements in the buildings and industrial sectors	International	Author declared no conflicts of interest.
Brown_2019	Brown, D., Sorrell, S., Kivimaa, P. (2019) Worth the risk? An evaluation of alternative finance mechanisms for residential retrofit, Energy Policy, Volume 128, pp. 418–430	Peer-reviewed. Narrative review	Typology and evaluation of finance mechanisms for residential energy efficiency retrofit.	International	UK EPSRC grant. Authors declared no conflict of interests
Curtin_2017	Curtin, J., McInerneya, C., Ó Gallachóirb, B. (2017) Financial incentives to mobilise local citizens as investors in low-carbon technologies: A systematic literature review, Renewable & Sustainable Energy Reviews, Volume 75, Issue 0, pp. 534-547	Peer-reviewed. Systematic review	Financial incentives for local citizens to invest in low-carbon technologies	International	Environmental Protection Agency project number 2014-SE-MS-1
Deason_2016	Deason, J et al (2016) Energy Efficiency Program Financing: Where it comes from, where it goes, and how it gets there, Lawrence Berkeley National Laboratory	Non- peer-reviewed. Report	Quantitative analysis of programmatic financing energy efficiency	United States	U.S. Department of Energy's Office of Energy Policy and Systems Analysis (EPSA)
Gooding_2016	Gooding, L., Gul, M.S. (2016) Energy efficiency retrofitting services supply chains: A review of evolving demands from housing policy, Energy Strategy Review, Volume 11, Issue 0, pp. 29-40	Peer-reviewed. Narrative review	Policy design for the energy efficiency retrofit services sector	United Kingdom	None mentioned

First Author_year	Reference	Study type	Main topic	Geographic. focus	Study funding, Conflict of interests
Hesselink_2019	Hesselink, L., Chappin, E. (2019) Adoption of energy efficient technologies by households – Barriers, policies and agent-based modelling studies, Renewable and Sustainably Energy Reviews, Volume 99, Issue 0, pp. 29-41	Peer-reviewed. Systematic review	Agent based modelling studies on the adoption of energy efficiency by households	International	European Union's Horizon 2020 research and innovation programme under grant agreement No 723716, project CHEETAH
Hor_2018	Hor, K., Rahmat, M.K. (2018) Analysis and recommendations for building energy efficiency financing in Malaysia, Energy Efficiency, Volume 11, Issue 1, pp. 79-95	Peer-reviewed. Narrative review	Financing and incentive mechanisms for energy efficiency in the building sector	Malaysia	The authors declare that they have no conflict of interest
James_2012	James, P. (2012) Overcoming barriers to low carbon dwellings: The need for innovative models of finance and service-provision, Environmental Development - Volume 2, Issue 1, pp. 6-17	Peer-reviewed. Narrative review	UK policies for reducing emissions in the residential building sector	United Kingdom	None mentioned
Shan_2017	Shan, M., Hwang, B., Zhu, L. (2017) A Global Review of Sustainable Construction Project Financing: Policies, Practices, and Research Efforts, Sustainability - Volume 9, Issue 12	Peer-reviewed. Systematic review	Sustainable construction project financing	United Kingdom, the United States, Singapore, and Australia	No external funding or conflict of interest
Sweatman_2010	Sweatman, P and Managan, K. (2010) Financing Energy Efficiency Building Retrofits, International Policy and Business Model Review and Regulatory Alternatives for Spain. Climate Strategy and Partners	Non- peer-reviewed. Report	Financing energy efficiency building retrofits	USA, UK Spain	None mentioned
UNECE_2015	UNECE (2015) Best Policy Practices for Promoting Energy Efficiency, United Nations Economic Commission for Europe	Non- peer-reviewed. Report	Best practice in existing energy efficiency policies	International	Prepared in framework of the UN Development Account project "Promoting Energy Efficiency Investments for Climate Change Mitigation and Sustainable Development"

Table 3. Summary of conclusions for the included studies

First Author_year	Study conclusions	Comments on relevance to the rapid review topic
Bertone_2016	The study found ten different types of finance methods applicable to retrofit projects: on-bill recovery; environmental upgrade finance; revolving loan funds; climate bonds; grants; interest rate buy-downs; loan loss reserve funds; insurance; energy services agreement; and green depreciation. Among the barriers to retrofitting public buildings discussed in the paper, two were highlighted:(i) a lack of consideration of the synergies available from the water-energy nexus and (ii) restricted access to effective financing mechanisms. The study provides a strategic roadmap for public building retrofits as well as a number of recommendations including the adoption of energy performance procurement and the use of revolving loan fund financing.	The study provides a useful taxonomy of finance mechanisms and provides a number of illustrative examples of the mechanisms used in practice. It also contains a decent, but not comprehensive, description of government incentives schemes for energy efficiency in Australia as of 2016. The authors claim that the best Australian retrofit financing scheme to date is the Melbourne '1200 Buildings Programme' program, an environmental upgrade financing scheme where the loan is repaid through municipal taxes to the City of Melbourne. However, it provides little analysis to support this claim. Internationally, they claim that the most successful system for financing retrofits appears to be the revolving loan fund system in the US.
Brown_2015	The study reviews information, financing, and regulatory policies that has been adopted to improve energy efficiency in the buildings and industrial sectors. Conclusions of the study include: recommending the adoption of tools and metrics such as levelized costs and the policy supply curve to fashion more effective energy efficiency policy solutions; the need for periodic updating of policies to respond to changing technology and market conditions; and the need for comprehensive compliance regimes.	Financing mechanisms are only an element of this study which covers a large range of policy levers for energy efficiency improvements in buildings and industry. The financing mechanisms section focuses on three types: Property Assessed Clean Energy (PACE) financing, energy savings performance contracts, and on-bill financing. However, it makes few comments on best practice.
Brown_2019	The paper develops a typology of financing mechanisms for residential retrofit, highlighting seven key design features: capital source; the type of financial instrument; the customer interface, the project performance requirements; the type of loan security and underwriting; the means of repayment and overall customer experience. They use the framework to describe six different finance mechanism: public loan /credit enhancement; on bill financing; Property Assessed Clean Energy (PACE); green mortgage; Energy Services Agreement (ESA); and community financing. They also use the framework to show how three design features may influence the success of a mechanism: simplicity and ease in customer experience; appealing to broader sources of value; and reducing the cost of capital.	This paper is the most relevant study of this rapid review. It entirely focuses on classifying and describing finance mechanisms for building retrofit and also provides insights on the success factors that may contribute towards best practice. It is also the most recent study in the rapid review and the paper's literature review supports the finding that "a comprehensive study of finance mechanisms for domestic retrofit is largely absent from the academic literature" (p.419).
Curtin_2017	The paper provides a systematic review of mobilizing low carbon investment by local citizen through a number of financial incentives: feed-in tariffs; quota-based schemes; feed in premium; tax incentives; grants and soft loans. They tabulate the strengths and weaknesses of these instruments and highlight the importance of considering the specific needs of local citizens in economic and financial incentive design. They find that feed-in tariffs, grants and tax incentives can be successful in increasing low carbon investments but that soft loans tend to be less useful. They also conclude that the studies reviewed tend not to systematically and consistently evaluate the impact of different economic and financial incentives. This limits the available conclusions on best practice for policy design.	The strength of this paper is that it is a systematic review. However, the focus is exclusively on public policy incentives schemes such as feed-in tariffs and tax rebates, and only the section on state soft loans is relevant from the perspective of financing mechanisms as defined in this review.

Deason_2016	The report collects data for energy efficiency financing in the U.S. that originated from five programmatic sources: on-bill programs; other utility financing programs; property assessed clean energy (PACE) programs; state energy office (SEO) revolving loan funds (RLF); and energy savings performance contracting (ESPC) programs. They find that ESPC represents about 85% of that total energy efficiency lending capital in 2014. The largest lending volumes are associated with those programs that have employed private capital, credit enhancements and interest rate buy-downs (IRB).	The report only provides data on the extent of operations of various programs in the USA and does not attempt to evaluate best practice of the different private financing mechanisms they examine.
Gooding_2016	The paper reviews a number of UK policies regimes concerning the energy efficiency retrofit services sector, including supply-side energy supplier obligation schemes and demand-side policies aimed at private home owners and housing associations. The paper evaluates them across five identified barriers to energy efficiency uptake. Among their results, they find that the Green Deal, an on-bill financing scheme involving no supplier obligations, with minimal regulation and public funding, performed least well in terms of their evaluative criteria. A key conclusion is that policies that focus simply on marginal financial incentives (such as soft loans) should be complemented by attention to how policy instruments more generally impact supply chains and end-users.	The paper provides a useful framework for evaluating policy options in terms of a number of energy efficiency barriers identified in the literature. The barriers considered include end user awareness, hidden costs or transaction costs, organisational barriers, barriers limiting the opportunity for innovation, and inertia. The paper also presents an interesting case study of the performance of on-bill financing. However, the coverage of other finance mechanisms in this paper is relatively limited.
Hesselink_2019	This systematic review found 23 studies on energy efficiency adoption using agent based modelling (ABM). They find that general energy efficiency barrier studies are largely centred on five areas impacting energy efficiency uptake: capital restrictions, limited information, high upfront cost, ignorance, inertia and other priorities. However, they find that ABM studies have mainly focused on subsidies, technology bans and information campaigns. Hence there are prospects for future ABM research on the take-up of energy efficiency investments to include considering other barriers.	While this paper offers little in terms of conclusions on best practice for financial mechanisms, it does provide a useful systematic review of an innovative, bottom-up modelling approach that could in the future be used investigate, among other factors, the role of financial incentives and finance mechanisms in energy efficiency uptake.
Hor_2018	The paper compares a number of energy efficiency policy schemes adopted in Malaysia: credit guarantees, interest rate subsidies; tax and stamp duty exemptions and grants. The most cost effective scheme was a targeted tax rebate scheme for commercial and domestic refrigeration and air conditioning. The authors make the case for the potential of on-bill financing as a commercial scheme to scale up the efforts currently being driven by various types of government supported schemes.	Although this paper is outside the geographic focus of this review and covers a limited range of finance mechanism, it does provide an exemplary analysis of the strengths and gaps of the programs, including government finance mechanisms that have been trialled in Malaysia.
James_2012	Examining energy efficiency policies in the UK, the paper concludes that existing policies for the UK residential sector are unlikely to result in deep and rapid emission reductions. The paper highlights a number of self-limiting conditions in existing policies, including the fact that Green Deal loans are only given when the loan payments are less than or equal to the energy cost savings. They paper argues that energy service company (ESCO) models hold promise for solving a number of the important energy efficiency barriers including hidden costs, risks of performance outcomes and upfront finance constraints. Another recommendation is that the current incentive structure of the energy market needs to be realigned to make ESCOs (and reducing energy consumption) more profitable for energy suppliers.	This is a useful survey and evaluation of U.K residential energy efficiency policies as of 2012. Finance mechanisms are only one element of this review, which primarily discusses energy efficiency incentive policies.

Shan_2017	The paper reviews the policies, practices, and research efforts for sustainable construction project financing. The paper looks at models of finance for sustainable buildings in a five-part taxonomy: bank loans; green bonds (particularly by multilateral banks); international assistance programs (e.g. The Global Environment Facility Trust Fund); government subsidies schemes and tax incentives; and private finance. They identified four significant research areas: identifying key stakeholders; advantages of implementing sustainable construction project financing along with associated barriers; classification of financial vehicles for sustainable construction; and new models and mechanisms of financing. They recognize five future directions for sustainable construction project financing research. This includes further research on developing best practices for sustainable construction project financing, since the limited uptake of sustainable construction project financing is partly due to stakeholder's knowledge limitations.	This was one of the three systematic review included in this rapid review and the only paper to focus on sustainable construction project finance. The review also included coverage of developing countries and the role of development banks.
Sweatman_2010	The report analyses three business models for energy efficiency retrofit: the owner financed model, the utility fixed repayment model and ESCO's energy performance model. They find the owner financed model scores the lowest in their evaluation scheme of addressing stakeholder interests, while the energy performance model seems to be best, particularly in addressing the customer's immediate interests. The main weakness for all three models is access to wholesale finance. Highlighting these and other challenges of the retrofit market, they propose a new business model called the aggregated investment model based, in part, on on-bill financing and the creation of 'bankable' energy efficiency assets that have broad access to the capital markets. The business model is targeted at the residential, multi-unit and SME markets. This business model is advocated partly because of its flexibility in different market environment and because it does not rely on any regulatory mandates.	This is the oldest of the papers included in the review and looks solely at commercial models of financing building retrofits. The focus is on business models but is relevant for this review due to the different financing mechanisms associated with each model. The report also has one of the more detailed analysis of different stakeholders that may be involved in buildings retrofits.
UNECE_2015	The report presents a collection of existing energy efficiency policies are claimed to stand out as best practice. They examine a broad set of policy areas: governance, finance, utilities, households, transport, and business. The report provides results of expert surveys on (perceived) effectiveness of energy policies in the EU. With respect to finance, the report provides some general evaluations and exemplar policies for a number of financing areas: government and leveraged loans finance; public-private finance from ESCOs; funds guarantees; risk sharing; fiscal policies (tax incentives rebates, etc); government grants; and international climate finance. For government and leverage loans, the three exemplars of best practice they give are: Germany KfW; EBRD Sustainable Energy Financing Facilities (SEFF); and the China Energy Efficiency Financing Programme (CHEEF). They highlight the benefits of ESCO type services which integrate financial and technical risks. This can smooth out conflicts of interests between consumers, service companies and financiers. The report emphasizes the importance of local context in the effective implementation of best practice policies.	The report covers a much wider set of concerns than the topic of finance mechanisms for building, including policies for energy efficiency in industries. Financial mechanisms for the building sector are a relatively small component of the report. The framework of attributes for best practice in energy efficiency policies may be useful. The four criteria are: (i) significant outcomes, including energy demand reductions (ii) complementarity with other efforts (iii) political alignment and palatability (iv) marketability.

Table 4. Taxonomy of finance mechanisms (based on Brown_2019)

	Features of the finance mechanism					
Type of finance mechanism	***Source of capital***	***Financial instrument***	***Point of sale***	***Repayment channel***	***Example schemes***	***Considered by study***
Public loan / credit enhancement	Government spending	Debt	Third party finance provider	Unsecured loan/equity release	HES and HEEPS equity loan (Scotland)	Bertone_2016; Brown_2019; Curtin_2017; Deason_2016; Hor_2018; UNECE_2015
	Public bank	Debt (bonds)	Retail bank	Unsecured loan	KfW CBRP (Germany)	
	Hybrid	Debt	Housing provider	Revolving phase then full repayment	JESSICA->LEEF (EU -> London, UK)	
On bill financing	Energy utility	Debt (sometimes securitized)	Energy utility	Energy bills	USA & Canada OBF Schemes	Bertone_2016; Brown_2015; Brown_2019; Deason_2016; Gooding_2016; Hor_2018; James_2012; Sweatman_2010; UNECE_2015
	Third party private sector	Debt	Third party finance provider		UK (OBF) Green Deal	
Property Assessed Clean Energy (PACE)	Municipal bond -> private capital	Debt (Bonds)	Contractor	Property taxes	RE:NEW Financial (US)	Bertone_2016; Brown_2015; Brown_2019; Deason_2016; Sweatman_2010; UNECE_2015
	Public bank	Debt	Contractor	Council Rate Notices	Melbourne '1200 Buildings Programme' (Aust)	
Green mortgage	Covered Bond Market	Mortgage (equity and debt)	Mortgage provider	Mortgage Payments	EMF Green mortgage project	Brown_2019; Shan_2017; Sweatman_2010
	Member Deposits	Equity			Ecology Building Society (UK)	
Energy Services Agreement (ESA)	ESCO->Public Bank	Debt &Equity	Contractor	Energy performance contract	RENESCO (Latvia)	Bertone_2016; Brown_2015; Brown_2019; Deason_2016; James_2012; Sweatman_2010; UNECE_2015
	ESCO -> institutional investor				SEA (Italy)	
Community financing	Member share issue	Equity	Contractor	Hire purchase agreement -> dividends	BHESCo (Brighton, UK)	Brown_2019

Resources, workload and timeline

Figure 2. Review team members

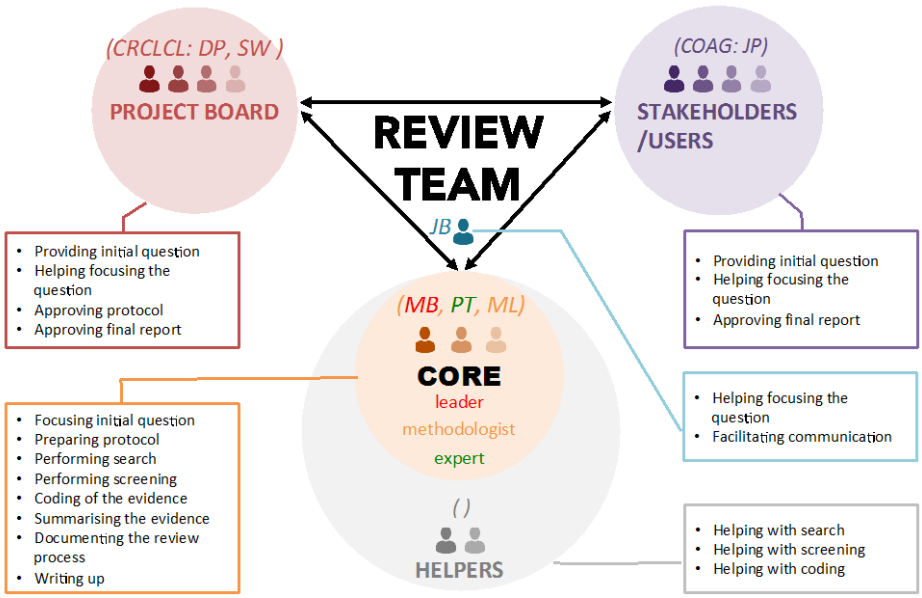


Figure3. Review timeline

Stage	March 2019				April 2019				May 2019				June 2019			
Stage1																
Stage2																
Stage3																

Table 5. Workloads (in hours) of the team members for each main review stage

Review Stage	ML	PT	MB	Total	Comments
Team formation	1	3	1		
Question refinement	2	3	1		
Protocol preparation	7	2	1		
Search and screening	14	14			
Data extraction	2	26			
Synthesis / Report	16	24	5		
Total	**42**	**71**	**8**		

Supplementary Information

Table S1. Table of search results in online databases other than Scopus and Web of Science

Source	Search string	Search date	N references screened	N systematic review family found and selected for checking full-text	N other reviews found and selected for checking full-text
OpenGrey (http://www.opengrey.eu/)	(("energy efficiency" OR "sustainable energy" OR "energy sustainability" OR "green energy" OR "renewable energy" OR "renewable electricity" OR "household energy" OR "green power" OR "energy program*" OR "energy behavior*" OR "energy consum*" OR "energy polic*" OR "energy us*" OR "energy initiativ*" OR "energy coneservation") AND (resident* OR house* OR home* OR building* OR apartm* OR unit* OR consumer* OR community* OR user* OR *occupan* OR "home*owner*" OR retrofit* OR renovat* OR improv* OR upgrad* OR insulat* OR solar*) AND (financ* OR loan* OR incentiv* OR repay* OR lease* OR grant* OR "one-bill" OR subsid* OR monetary OR fund* OR "PACE" OR "ESPC" OR "ESCO"))	18/04/2019	218	0	0
Informit (including APO)https://search.informit.com.au/	resident* AND ("energy efficiency") AND financ*	18/04/2019	44	0	0
ProQuest Dissertation & Theses Global (PQDT Global, http://www.proquest.com/products-services/cpi-set-c.html)	noft((("meta-analy*" OR "meta analy*" OR "metaanaly*" OR "meta-review*" OR (systematic* NEAR/2 review*) OR (systematic* NEAR/2 map*) OR (evidence NEAR/2 review*) OR (evidence* NEAR/2 map*) OR (scoping NEAR/2 review) OR (rapid NEAR/2 review)) AND ("energy efficiency" OR "sustainable energy" OR "energy sustainability" OR "green energy" OR "renewable energy" OR "renewable electricity" OR "household energy" OR "green power" OR "energy program*" OR "energy	18/04/2019	6	0	0

	behavior*" OR "energy consum*" OR "energy polic*" OR "energy us*" OR "energy initiativ*" OR "energy coneservation") AND (resident* OR house* OR home* OR building* OR apartm* OR unit* OR consumer* OR community* OR user* OR occupan* OR "homeowner*" OR retrofit* OR renovat* OR improv* OR upgrad* OR insulat* OR solar*) AND (financ* OR loan* OR incentiv* OR repay* OR lease* OR grant* OR "one-bill" OR subsid* OR monetary OR fund* OR "PACE" OR "ESPC" OR "ESCO"))); LAST 10 YEARS				
WorldCatDissertations (http://www.worldcat.org)	(("meta-analy*" OR "meta analy*" OR "metaanaly*" OR "meta-review*" OR " systematic review" OR " systematic map" OR " evidence review " OR "evidence map" OR "scoping review" OR "rapid review ") AND ("energy efficiency" OR "sustainable energy" OR "energy sustainability" OR "green energy" OR "renewable energy" OR "renewable electricity" OR "household energy" OR "green power" OR "energy program*" OR "energy behavior*" OR "energy consum*" OR "energy polic*" OR "energy us*" OR "energy initiativ*" OR "energy coneservation") AND (resident* OR house* OR home* OR building* OR apartm* OR unit* OR consumer* OR community* OR user* OR *occupan* OR "home*owner*" OR retrofit* OR renovat* OR improv* OR upgrad* OR insulat* OR solar*) AND (financ* OR loan* OR incentiv* OR repay* OR lease* OR grant* OR "one-bill" OR subsid* OR monetary OR fund* OR "PACE" OR "ESPC" OR "ESCO"))	18/04/2019	6	0	1
EBSCO Open Dissertations (https://www.ebsco.com/products/research-databases/ebsco-open-dissertations)	(("energy efficiency" OR "sustainable energy" OR "energy sustainability" OR "green energy" OR "renewable energy" OR "renewable electricity" OR "household energy" OR "green power" OR "energy	18/04/2019	3	0	0

	program*" OR "energy behavior*" OR "energy consum*" OR "energy polic*" OR "energy us*" OR "energy initiativ*" OR "energy coneservation") AND (resident* OR house* OR home* OR building* OR apartm* OR unit* OR consumer* OR community* OR user* OR *occupan* OR "home*owner*" OR retrofit* OR renovat* OR improv* OR upgrad* OR insulat* OR solar*) AND (financ* OR loan* OR incentiv* OR repay* OR lease* OR grant* OR "one-bill" OR subsid* OR monetary OR fund* OR "PACE" OR "ESPC" OR "ESCO"))				
Google Scholar	1. (building “energy efficiency" financing | loan | subsidy | incentive "systematic review" | "meta analysis" | "evidence review" | "evidence map" | "scoping review" | "rapid review") 2. building “energy efficiency" financing | loan | subsidy | incentive | grant | lease | funding	18/04/2019	1000	0	0
Total:			1277		

Table S2. Table of snowballing results

Snowballing from: First Author_year	Snowballing from: Title	N citing papers screened	N cited papers screened	N total screened	N papers selected for checking full-text
Bertone_2016	State-of-the-art review revealing a roadmap for public building water and energy efficiency retrofit projects	11	80	91	0
Brown_2016	Innovative energy-efficiency policies: an international review	9	80	89	1
Curtin_2017	Financial incentives to mobilise local citizens as investors in low-carbon technologies: A systematic literature review	6	80	86	1
Gooding_2016	Energy efficiency retrofitting services supply chains: A review of evolving demands from housing policy	6	78	84	0
Hesselink_2019	Adoption of energy efficient technologies by households – Barriers, policies and agent-based modelling studies	2	53	55	0
Hor_2018	Analysis and recommendations for building energy efficiency financing in Malaysia	1	21	22	0
James_2012	Overcoming barriers to low carbon dwellings: The need for innovative models of finance and service-provision	11	22	33	0
Shan_2017	A Global Review of Sustainable Construction Project Financing: Policies, Practices, and Research Efforts	6	80	86	2
Total:		52	494	546	4

Table S3. Table of the excluded studies at the full-text screening stage, with reasons

First Author_year	Reference	Reason for exclusion
Andor_2018	Behavioral Economics and Energy Conservation – A Systematic Review of Non-price Interventions and Their Causal Effects, Ecological Economics Volume 148, pp. 178–210	Limited discussion of financial models
Berghorn_2016	Risk framework for energy performance contracting building retrofits, Journal of Green Building, Volume 11, Issue 2, pp. 93-115.	Only examines energy performance contracting (EPC)
Bergman_2009	UK microgeneration. Part I: Policy and behavioural aspects, Proceedings of the Institution of Civil Engineers – Energy, Volume 162, Issue 1, February 2009, pp. 23-36	Limited discussion of financial models
Brown_2018	Business models for residential retrofit in the UK: a critical assessment of five key archetypes, Energy Efficiency, Volume 11, Issue 6, pp. 1497–1517	Limited discussion of financial models
Czakó_2012	Evolution of Hungarian residential energy efficiency support programmes: Road to and operation under the Green Investment Scheme, Energy Efficiency, Volume 5, Issue 2, pp.163–178	Limited number of financial models examined.
Darko_2017	Review of Barriers to Green Building Adoption, Sustainable Development, Volume 25, Issue 3, pp. 167-179	Provides some discussion of financial incentives but limited discussion of financial models
Huo_2017	Analytical Review of Green Building Studies, Journal of Green Building, Volume 12, Issue 2, pp. 130-148.	Limited discussion of financial models
Mazzucato_2017	Public financing of innovation: new questions, Oxford Review of Economic Policy, Volume 33, Issue 1, pp.24–48,	Provides a macro-transition level of analysis and contains no specific details on financial mechanisms
Polzin_2017	Mobilizing private finance for low-carbon innovation – A systematic review of barriers and solutions. Renewable and Sustainable Energy Reviews, Volume 77, pp. 525-535	Covers general economy wide barriers and solution to energy efficiency uptake and is not specific on finance
Thompson_2010	RE/RETRO-Commissioning: The best kept secret you can no longer afford not to know, Strategic Planning for Energy and the Environment, Volume 31, Issue 2, pp.49-66	Limited discussion of financial models
Zhao_2016	Business model innovation for delivering zero carbon buildings, Sustainable Cities and Society, Volume 27, pp. 253-262	Limited discussion of financial models
Lesjak_2014	Analysis and review of the best practices and lessons learned on EE Financing from Malaysia and other countries, Mimeo for Building Sector Energy Efficiency Project (BSEEP)	Non-peer reviewed with a main focus on Malaysia. However, it contains a useful table on energy efficiency finance programs in the appendix

CCCUK_2016	Annex 3 – Best Practice in Residential Energy Efficiency Policy: A Review of International Experience 2016, from Committee on Climate Change UK, Next Steps for UK Heat Policy	Limited discussion on energy efficiency finance mechanisms
Deutsche_Bank_ 2012	United States Building Energy Efficiency Retrofits, White Paper for the Rockefeller Foundation.	Non-peer reviewed

Table S4. Quality assessment tool.

An adapted AMSTAR 2 (Shea et al. 2017) checklist used to asses quality and risk of bias of individual systematic reviews / meta-analyses included for our meta-review.

Question (recommendations)	Decision rules and comments
Q1. Are the research questions and inclusion criteria for the review clearly delineated?	1 = "Yes" = Who (Population/Subject), What (Intervention, Comparator group, Outcome), Where and When described, as relevant to the review questions.
	0.5 = "Can't answer / not sure / partially" = Cannot decide between "yes" and "no", basing on the information provided in the paper.
	0 = "No" = research question and inclusion criteria not outlined in detail.
Q2. Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review and did the report justify any significant deviations from the protocol?	1 = "Yes" = The authors state that they had a written protocol or guide that included ALL the following: review question(s), a search strategy, inclusion/exclusion criteria, risk of bias assessment.
	0.5 = "Can't answer / not sure / partially" = The authors state that they had a written protocol or guide that included ALL the following: review question(s), a search strategy, inclusion/exclusion criteria, a risk of bias assessment.
	0 = "No" = no mention of *a priori* design of the systematic review, as listed above.
Q3. Did the review authors explain their selection of the study designs for inclusion in the review?	1 = "Yes" = explicit justification of the study designs/types included in the review.
	0.5 = "Can't answer / not sure / partially" = more than one online source but no supplementary sources or one online source and one supplementary source. Cannot decide between "yes" and "no", basing on the information provided in the paper.
	0 = "No" = explicit justification of the study designs/types included in the review.
Q4. Did the review authors use a comprehensive literature search strategy?	1 = "Yes" = searched at least 2 databases (relevant to research question), provided key word and/or search strategy, justified publication restrictions (e.g. language), AND searched the reference lists / bibliographies of included studies, searched trial/study registries, included/consulted content experts in the field, where relevant, searched for grey literature, conducted search within 24 months of completion of the review.
	0.5 = "Can't answer / not sure / partially" = searched at least 2 databases (relevant to research question), provided key word and/or general search strategy, justified publication restrictions (e.g., language).

	0 = “No” = no information on search strategy, or not fulfilling criteria for “Yes” and “Partially”.
Q5. Did the review authors perform study selection in duplicate?	1 = “Yes” = either ONE of the following: at least two reviewers independently agreed on selection of eligible studies and achieved consensus on which studies to include OR two reviewers selected a sample of eligible studies and achieved good agreement (at least 80%), with the remainder selected by one reviewer.
	0.5 = “Can’t answer / not sure / partially” = Cannot decide between “yes” and “no”, basing on the information provided in the paper.
	0 = “No” = only one reviewer involved in the study selection or no description how many reviewers participated in study selection.
Q6. Did the review authors perform data extraction in duplicate?	1 = “Yes” = either ONE of the following: at least two reviewers achieved consensus on which data to extract from included studies OR two reviewers extracted data from a sample of eligible studies and achieved good agreement (at least 8 %), with the remainder extracted by one reviewer.
	0.5 = “Can’t answer / not sure / partially” = Cannot decide between “yes” and “no”, basing on the information provided in the paper.
	0 = “No” = only one reviewer involved in the study selection or no description how many reviewers participated in data extraction.
Q7. Did the review authors provide a list of excluded studies and justify the exclusions?	1 = “Yes” = provided a list of all potentially relevant studies that were read in full-text form but excluded from the review AND justified the exclusion from the review of each potentially relevant study.
	0.5 = “Can’t answer / not sure / partially” = only provided a list of all potentially relevant studies that were read in full-text form but excluded from the review, but not justified the exclusion from the review of each potentially relevant study that were read in full-text.
	0 = “No” = No list of studies excluded at a full-text stage.
Q8. Did the review authors describe the included studies in adequate detail?	1 = “Yes” = ALL the following: Who (Population), What (Intervention, Comparator group, Outcome), Where and When described in detail.
	0.5 = “Can’t answer / not sure / partially” = Who (Population), What (Intervention, Comparator group, Outcome), Where and When briefly described, or only some of these described in detail. Cannot decide between “yes” and “no”, basing on the information provided in the paper.
	0 = “No” = no, or partial description of the included studies
Q9. Did the review authors use a satisfactory technique for assessing the risk of bias (RoB) in individual studies that were included in the review?	1 = “Yes” = specifically mentions RoB assessment of individual included studies.
	0.5 = “Can’t answer / not sure / partially” = Cannot decide between “yes” and “no”, basing on the information provided in the paper. RoB mentioned or not sufficiently assessed (e.g. if multiple sources of bias potentially present, but not all assessed).
	0 = “No” = no mention of RoB assessment of individual included studies.
	[RoB sources: from confounding, from selection bias, from exposure bias, from selective reporting of outcomes, selection of the reported result from among multiple measurements or analyses of a specified

	outcome].
Q10. Did the review authors report on the sources of funding for the studies included in the review?	1 = "Yes" = Must have reported on the sources of funding for individual studies included in the review. Note: Stating that the reviewers looked for this information but it was not reported by study authors, also qualifies.
	0.5 = "Can't answer / not sure / partially" = sources of funding mentioned for individual studies included in the review, or reported only for some of the included studies. Cannot decide between "yes" and "no", basing on the information provided in the paper.
	0 = "No" = no report of the sources of funding for individual studies included in the review.
Q11. If meta-analysis was performed did the review authors use appropriate methods for statistical combination of results?	1 = "Yes" = The authors justified combining the data in a meta-analysis AND they used an appropriate technique to combine study results and adjusted for heterogeneity if present *AND* investigated the causes of any heterogeneity or adjusted for heterogeneity or confounding if present.
	0.5 = "Can't answer / not sure / partially" = Requirements for "Yes" only partially fulfilled. Cannot decide between "yes" and "no", basing on the information provided in the paper.
	0 = "No" = no justification of meta-analysis or inappropriate statistical methods were used for quantitatively combining and analysing the data, heterogeneity not assessed.
	N/A = "Not Applicable" = No meta-analysis conducted.
Q12. If meta-analysis was performed, did the review authors assess the potential impact of RoB in individual studies on the results of the meta-analysis or other evidence synthesis?	1 = "Yes" = included only low risk of bias studies OR the authors performed analyses to investigate possible impact of RoB on summary estimates of effect.
	0.5 = "Can't answer / not sure / partially" = Cannot decide between "yes" and "no", basing on the information provided in the paper.
	0 = "No" = no assessment of the potential impact of RoB.
	N/A = "Not Applicable" = No meta-analysis conducted.
Q13. Did the review authors account for RoB in individual studies when interpreting/ discussing the results of the review?	1 = "Yes" = included only low risk of bias studies OR the review provided a discussion of the likely impact of RoB on the results.
	0.5 = "Can't answer / not sure / partially" = Cannot decide between "yes" and "no", basing on the information provided in the paper.
	0 = "No" = no discussion of the potential impact of RoB in individual studies.
Q14. Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?	1 = "Yes" = There was no significant heterogeneity in the results OR if heterogeneity was present the authors performed an investigation of sources of any heterogeneity in the results and discussed the impact of this on the results of the review.
	0.5 = "Can't answer / not sure / partially" = Cannot decide between "yes" and "no", basing on the information provided in the paper.
	0 = "No" = No explanation or discussion of heterogeneity present in the results.
Q15. If they performed quantitative synthesis did the review authors	1 = "Yes" = The authors performed graphical or statistical tests for

carry out an adequate investigation of publication bias (small study bias) and discuss its likely impact on the results of the review?	publication bias and discussed the likelihood and magnitude of impact of publication bias.
	0.5 = “Can’t answer / not sure / partially” = more than one online source but no supplementary sources or one online source and one supplementary source. Cannot decide between “yes” and “no”, basing on the information provided in the paper.
	0 = “No” = The authors did not perform any tests for publication bias and did not discuss potential impact of publication bias.
	N/A = “Not Applicable” = No meta-analysis conducted.
Q16. Did the review authors report any potential sources of conflict of interest, including any funding they received for conducting the review?	1 = “Yes” = The authors reported no competing interests OR the authors described their funding sources and how they managed potential conflicts of interest.
	0.5 = “Can’t answer / not sure / partially” = Cannot decide between “yes” and “no”, basing on the information provided in the paper.
	0 = “No” = The authors did not provide statement on competing interests and funding sources, and how they managed potential conflicts of interest.

Table S5. Responses to quality assessment questions from Table S3 coded for each of the included studies.

The responses to each question were coded numerically and color-coded as following: green = 1 = “Yes”; yellow = 0.5 = “Can’t answer / not sure / partially”, red = 0 = “No”, grey = N/A = “Not Applicable”, * denotes item relevant to risk of bias.

First Author _year	Q1	Q2 *	Q3	Q4	Q5 *	Q6 *	Q7	Q8	Q9 *	Q10 *	Q11	Q12 *	Q13 *	Q14	Q15 *	Q16 *
Curtin_2017 *Overall quality: C* *Risk of bias: high*	1	0	0.5	0.5	0	0	0	1	0	0	NA	NA	0	1	NA	1
Hesselink_2019 *Overall quality: C* *Risk of bias: high*	1	0	0.5	0	0	0	0	1	0	0	NA	NA	0	1	NA	1
Shan_2017 *Overall quality: C* *Risk of bias: high*	1	0	0.5	0.5	0	0	0	0.5	0	0	NA	NA	0	1	NA	1

References

Bertone, E. O. Sahin, R. A. Stewart, P. Zou, M. Alam, E. Blair (2016) State-of-the-art review revealing a roadmap for public building water and energy efficiency retrofit projects, Renewable & Sustainable Energy Reviews - Volume 75, Issue 0, pp. 534-547

Brown, M. (2015) Innovative energy-efficiency policies: an international review, WIREs Energy Environ, Volume 4, pp.1–25

Brown, D., Sorrell, S., Kivimaa, P. (2019) Worth the risk? An evaluation of alternative finance mechanisms for residential retrofit, Energy Policy, Volume 128, pp. 418–430

Curtin, J., McInerneya, C., Ó Gallachóirb, B. (2017) Financial incentives to mobilise local citizens as investors in low-carbon technologies: A systematic literature review, Renewable & Sustainable Energy Reviews, Volume 75, Issue 0, pp. 534-547

Deason, J et al (2016) Energy Efficiency Program Financing: Where it comes from, where it goes, and how it gets there, Lawrence Berkeley National Laboratory

Gooding, L., Gul, M.S. (2016) Energy efficiency retrofitting services supply chains: A review of evolving demands from housing policy, Energy Strategy Review, Volume 11, Issue 0, pp. 29-40.

Haby, M.M., Chapman, E., Clark, R., Barreto, J., Reveiz, L., Lavis, J.N., 2016. What are the best methodologies for rapid reviews of the research evidence for evidence-informed decision making in health policy and practice: A rapid review. Heal. Res. Policy Syst. https://doi.org/10.1186/s12961-016-0155-7

Hesselink, L., Chappin, E. (2019) Adoption of energy efficient technologies by households – Barriers, policies and agent-based modelling studies, Renewable and Sustainably Energy Reviews, Volume 99, Issue 0, pp. 29-41

Hor, K., Rahmat, M.K. (2018) Analysis and recommendations for building energy efficiency financing in Malaysia, Energy Efficiency, Volume 11, Issue 1, pp. 79-95

James, P. (2012) Overcoming barriers to low carbon dwellings: The need for innovative models of finance and service-provision, Environmental Development - Volume 2, Issue 1, pp. 6-17

Ouzzani, M., Hammady, H., Fedorowicz, Z., Elmagarmid, A., 2016. Rayyan—a web and mobile app for systematic reviews. Syst. Rev. https://doi.org/10.1186/s13643-016-0384-4

Sarrami-foroushani, P., Travaglia, J., Debono, D., Clay-williams, R., & Braithwaite, J. (2015) “Scoping Meta-Review : Introducing a New Methodology.” Clinical And Translational Science - Volume 8, Issue 1, pp. 77–81

Shan, M., Hwang, B., Zhu, L. (2017) A Global Review of Sustainable Construction Project Financing: Policies, Practices, and Research Efforts, Sustainability - Volume 9, Issue 12

Shea, B.J., Reeves, B.C., Wells, G., Thuku, M., Hamel, C., Moran, J., Moher, D., et al. (2017) “AMSTAR 2: A Critical Appraisal Tool for Systematic Reviews That Include Randomised or Non-Randomised Studies of Healthcare Interventions, or Both.” BMJ (Clinical Research Ed.) 358 (September). British Medical Journal Publishing Group: j4008

Sweatman, P and Managan, K. (2010) Financing Energy Efficiency Building Retrofits, International Policy and Business Model Review and Regulatory Alternatives for Spain. Climate Strategy and Partners.

UNECE (2015) Best Policy Practices for Promoting Energy Efficiency, United Nations Economic Commission for Europe