Environmental *Change* Institute
School of Geography and the Environment

The Role of the Forward Capacity Market in Promoting Electricity Use Reduction

Case studies of the Electricity Demand Reduction (EDR) Pilot in the UK and international schemes in North America and Europe

Yingqi Liu

Thesis submitted in partial fulfilment of the requirements for the degree of
Doctor of Philosophy at the University of Oxford

St John's College, Oxford

Trinity Term, 2017

To my dearest parents, for always being there

献给我最亲爱的父母，感谢一如既往的鼓励和支持

Abstract

Electricity use reduction is at the heart of an energy policy landscape increasingly defined by climate change, security and affordability. With its potential of peak demand reduction, it can be used as a cost-effective alternative to generation for contributing to capacity adequacy. In many restructured electricity markets, the forward capacity market is established as a solution to ensure capacity adequacy, with some of them allowing electricity use reduction to compete against other resources. To promote electricity use reduction, financial incentives for investment in end-use electric energy efficiency (EE) are crucial.

This thesis focuses on one novel approach of relying on the forward capacity market to incentivise electric efficiency investment, which is trialled in the Electricity Demand Reduction (EDR) Pilot in the UK. It aims to examine the role of the forward capacity market in promoting electricity use reduction, by asking two broad research questions: 1) whether the forward capacity market can serve as a *primary* policy vehicle to give financial incentives to support electricity use reduction; and 2) whether, as one mechanism for ensuring capacity adequacy, it can promote electricity use reduction *as a capacity resource*.

Case studies are conducted of the EDR Pilot, the Great Britain Capacity Market, ISO New England (ISO-NE), PJM and international electric efficiency schemes. They demonstrate that the forward capacity market, with its focus on peak savings and a savings-based approach for providing financial incentives, only plays a minor role in advancing the objective of incentivising investment in electric EE measures. The general design features of the forward capacity market pose higher requirements of participation, which may create barriers for some key customer segments to access financial incentives or target specific efficiency measure. The capacity payment, under the current market structure, may only provide a lukewarm incentive for customers to strengthen their capabilities to access support from the forward capacity market. However, it is valuable to integrate electricity use reduction in the forward capacity market. It is a viable mechanism to reward the capacity value of electricity use reduction, which requires the appropriate definition of capacity product, regulatory support for electricity use reduction and the removal of participation barriers.

Acknowledgements

This research has been an amazing journey of discovery, not only in a field I am passionate about but also about friendship, culture and myself. The thesis would not be possible without the support and guidance of many great individuals throughout the journey.

I would like to express my deep gratitude to my supervisors, Professor Nick Eyre and Dr Sarah Darby, for their inspirational ideas, motivating guidance and critical feedback, at every stage of my research. By always encouraging me to be adventurous and think about the 'big picture', they taught me how to be a better academic and communicator. It is such an invaluable experience to have fresh ideas and energy, after each supervisory meeting. I am also extremely grateful for their immense care and support, especially as I steer my research during times of obstacles.

I would like to thank Dr Brenda Boardman, Dr Jan Rosenow, Dr Phil Grünewald and Dr Kersty Hobson for their great advice and stimulating discussions at the transfer and confirmation stages of my DPhil. Their contributions of ideas and support make very valuable inputs to this thesis.

I feel privileged and fortunate to be part of the Lower Carbon Futures Group at the Environmental Change Institute. My colleagues' enthusiasm for their research is contagious and motivational. I am grateful for their unreserved help and support, particularly that of Dr Marina Topouzi and Dr Gavin Killip, in designing my survey and understanding the DPhil processes. I would like to thank all my colleagues for their support for the 'brown bag' seminars I helped organise in my second year. It is an incredibly fun group to be with – I think I am getting better with the English humour.

I owe my thanks to all the participants in my survey and interviews, and all the peer reviewers for my published papers. Their insightful thoughts and comments are valuable to this thesis.

Finally, I am hugely indebted to my family. This journey would not have been possible without the enormous, unconditional support from my parents and grandparents – thanks so much for always being there, and always encouraging me to chase my dreams! I know that I will have all their support in every step I take in this journey and beyond. To all my dear friends in the UK and beyond, thanks so much for making the past few years amazingly unforgettable – whether it is my first camping trip in Wales, the amazing trips to China and the U.S., or taking the first plunge into the sea off Cornwall and the Isis River (and staying sub-aqua)! I would like to express special thanks to Jonathan Balls, Viresh Patel, Victoria Wyllie De Echeverria, Katherine Fender, Saher Hasnain, Scott McDonald, Samuel Hampton, Laura Brinker, Freya Stanley-Price, Rob Pettinger, Sarah Worley-Hill, Rachel Ambrose, Liwen Wang, Qiong Lu, Xi Hu, Jing Hu, Guanli Zhang, Jiani He, Sen Li, Tingting Wang, Fei Guo, Xiawei Liao, Zichen Zhang and Yin Yang, amongst others. Many thanks for the amazing company to get me through the DPhil, the sharing of laughter and tears (while staying dry), and the timely pub visits.

I would like to thank the China Scholarship Council and the China Oxford Scholarship Fund for their generous support of this research.

Publications

This thesis is comprised of four papers that have been published in or are under review by peer-review academic journals:

Paper 1: Liu, Y., 2015. Seasonal relationship of peak demand and energy impacts of energy efficiency measures—a review of evidence in the electric energy efficiency programmes. Energy Efficiency, 1-21.

Paper 2: Liu, Y. (under review). Incentivising electricity use reduction: empirical evidence of benefits and limitations of savings-based approach for incentivising electric energy efficiency in North America and Europe. Energy Policy.

Paper 3: Liu, Y., 2018. Forward capacity market to promote electricity use reduction in the residential sector? A case study of potential of social housing participation in the Electricity Demand Reduction Pilot in the UK. Energy Efficiency. Available online on 15 January 2018.

Paper 4: Liu, Y., 2017. Demand response and energy efficiency in the capacity resource procurement: Case studies of forward capacity markets in ISO New England, PJM and Great Britain. Energy Policy 100, 271-282.

Table of contents

Figures

Tables

List of abbreviations

CCGT:	Closed-cycle gas turbine
CERT:	Carbon Emission Reduction Target
C&I:	Commercial and industrial
CONE:	Cost of new entry
CWI:	Cavity wall insulation
DECC:	Department of Energy and Climate Change
DLC:	Direct load control
DSBR:	Demand Side Balancing Reserve
DSIRE:	Database of State Incentives for Renewables and Efficiency
DSM:	Demand-side management
DSR:	Demand-side response
DR:	Demand response
DUKES:	Digest of United Kingdom Energy Statistics
ECO:	Energy Company Obligation
EDR:	Electricity Demand Reduction Pilot
EE:	Energy efficiency
EERS:	Energy Efficiency Resource Standards
ESOS:	Energy Savings Opportunity Scheme
ESCos:	Energy service companies
EU:	European Union
FCM:	Forward Capacity Market
FERC:	Federal Energy Regulatory Commission
GB:	Great Britain
HOU:	Hours-of-use
HVAC:	Heating, ventilation and air conditioning
ILR:	Interruptible Load for Reliability

IOUs:	Investor-owned utilities
IPMVP:	International Performance Measurement and Verification Protocol
IRP:	Integrated resource planning
ISO:	Independent system operator
ISO-NE:	ISO New England
LSEs:	Load Serving Entities
MISO:	Midcontinent Independent System Operator
M&V:	Measurement and verification
NDCs:	Nationally Determined Contributions
OECD:	Organisation for Economic Co-operation and Development
PJM:	Pennsylvania New Jersey Maryland Interconnection LLC
REED:	Regional Energy Efficiency Database
RHI:	Renewable Heat Incentive
RHPP:	Renewable Heat Premium Payment
RPM:	Reliability Pricing Mechanism
RTO:	Regional transmission organisation
SAP:	Standard Assessment Procedure
SBI:	Savings-based incentive
STOR:	Short-Term Operating Reserve
SWI:	Solid wall insulation
T&D:	Transmission and distribution
TOU:	Time-of-tariff
TRM:	Technical Reference Manual
VRR:	Variable resource requirement

1 | Introduction

Electricity use reduction is at the heart of policy efforts to reduce carbon emissions and can accrue benefits to customers and the society (e.g. economic productivity, fuel poverty reduction). For promoting electricity use reduction, a multitude of public policies (e.g. building regulation and product standards, financing, labelling and feedback) are typically introduced to address the market barriers faced by customers in investing in electric energy efficiency (EE) measures. Often amongst these policies are financial incentive schemes (e.g. rebate, discount and grant) playing a salient role in alleviating the financial barriers of EE improvement (e.g. upfront cost, payback).

Meanwhile, with an increasing concern for the reliability and economics of electric system, electricity use reduction can also be a cost-effective alternative to generation by reducing system peak demand and contributing to the capacity adequacy. While this concept is hardly new, it has gained traction in many restructured markets coming to face the issue of capacity adequacy or ‘missing money’ (Section 2.4). Several markets have established forward capacity markets as one solution for ensuring capacity adequacy to meet system peak demand and reserve margin, by procuring capacity resources by competitive auctions. Against this background, many forward capacity markets (e.g. ISO New England, PJM and Great Britain) allow demand-side resources including electricity use reduction to compete against other resources types in capacity auctions. This trend gives rise to the debate on how the market needs to be designed to remove barriers for these demand-side resources and unlock their value (Section 2.5 and Chapter 7).

Traditionally, designing a financial incentive scheme to encourage electricity use reduction is beyond the realm of liberalised electricity market (Section 2.5). A financial incentive scheme is part of a regulatory process imposing energy-saving obligations on utilities or public agencies – while it may well achieve energy- and peak-savings, these impacts are not treated as commodity products that can be traded in a liberalised electricity market. In places with a forward capacity market, allowing electricity use reduction to offer into capacity auctions and compete with other resources links two otherwise separate research fields – on one hand, it is part of a reform in the design of electricity markets; on the other, as noted in IEA (2017), it constitutes a new source of financial incentives that remunerates projects based on verifiable peak savings.

However, such an innovation in policy design has been taken to a new arena by the Electricity Demand Reduction (EDR) Pilot in the UK that explores whether a forward capacity market can play a *major* part in incentivising investment in electric EE measures. In 2014, the EDR Pilot has been established by the then Department of Energy and Climate Change (DECC) to procure and reward peak savings from electric EE projects, in a similar way with the Great British (GB) Capacity Market (see Section 6.2 for the detailed description of the EDR design). It is novel in that, apart from testing whether electric EE can be integrated in the GB Capacity Market as a capacity resource, it attempts to use the forward capacity market as a *primary* vehicle for providing financial incentives to electric EE investment – it is the first in the world to explore this policy proposition. In a sense, it uses a policy design mostly concerned with peak savings to address issues related to overall energy savings.

Against these novel policy developments, this thesis focuses on a central question: *what role the forward capacity market can play in promoting electricity use reduction*. More specifically, there are two dimensions:

- Whether a forward capacity market can be relied on as a *primary vehicle* to give financial incentives to encourage investment in electric EE measures; and
- How the mechanism should be designed to promote electricity use reduction *as a capacity resource* in a forward capacity market.

It draws on empirical evidence in the EDR Pilot, international EE incentive schemes and forward capacity markets in the UK and the U.S. It contributes to not only the literature on the design of electric EE incentive schemes but also the debate on the integration of electricity use reduction in a restructured electricity market. More importantly, it aims to 'demystify' the assumption by the UK government that a capacity market would be an important driver *on its own* for EE investment, without a need for additional regulatory support (e.g. supplier obligation). For countries that are contemplating a forward capacity market, this thesis aims to provide empirical lessons for whether removing barriers for electricity use reduction in capacity auctions would be a 'silver bullet' for encouraging EE investment (i.e. whether allowing electric EE resources to bid in forward capacity auctions would make it unnecessary to institute other financial incentive schemes), and whether other regulatory provisions are still needed.

It is also worth mentioning what this thesis is not about. First, that the issue of *additionality*, i.e. the extent to which the investment in electric EE measures takes place because of any given financial incentive scheme, is not the focus of this thesis. The opportunity to offer peak savings from electric EE projects in capacity auctions constitutes a new type of incentive. Understanding whether projects being put forward would be 'additional' to what would have happened anyway is a key priority for evaluating the outcomes and design of incentive schemes (e.g. economic efficiency). However, although the influence of an additionality requirement (e.g. minimum payback) on the procurement of EE resources is considered (see Chapter 5 and 6), this thesis focuses on whether a forward capacity market would be an *effective* tool to procure electric EE projects and their capacity (Section 1.1), and less on *its economic efficiency*, while the latter would be a valuable area for further research. Moreover, the practical constraints (e.g. time and resources) make it difficult for this thesis to do any detailed additionality analysis by looking at *specific* market conditions and related schemes for the covered cases, while the main aim is to synthesise high-level lessons shared across these cases.

Second, this thesis does not focus on the debate on whether a forward capacity market should be established in the first place (Section 2.4). It is mainly concerned with the role of a forward capacity market in promoting electricity use reduction, *if* indeed a decision is taken to set up such a market construct.

For the remainder of this chapter, the research objectives and questions are further explained before the overall argument and thesis structure (e.g. how four papers are tied together) is presented. But prior to that, it is useful to define some key terms. Table 1.1 defines key terms used in this thesis. Here, *electricity use reduction* is defined as reduction in electricity use from a counterfactual baseline[1]. Four points are worth emphasis:

- First, *electricity use reduction* refers to *overall savings* in electricity use (i.e. kWh), regardless of when savings occur. Savings coincident with system peak (i.e. highest system electricity demand) can result in *peak demand reduction* or *peak savings* (i.e. kW). Depending on characteristics of electricity use and exogenous factors (e.g. weather and climate), system peak demand can happen in the summer (e.g. California, PJM primarily due to air conditioning) or the winter (e.g. GB, British Columbia largely due to lighting).

- Second, it focuses on the *outcome*, i.e. lower electricity use, which should be able to be measured or verified in accordance with standard protocols.

- Third, it emphasises deliberate *actions or interventions* to bring about the reduction – it is a relative term in that it compares with what the electricity use *would have been*, had there not been such actions or interventions (i.e. counterfactual baseline). As discussed in Chapter 2, two types of actions or interventions can achieve reduction: 1) deliberate user conservation (i.e. lower energy service level); and 2) investment in electric equipment with higher efficiency rating or measures that can reduce overall electricity use for the same level of energy service (e.g. improved industrial process, insulation for electrically heated properties). The latter can be referred to as *electric energy efficiency measures or investment* (or *electric EE*), which is the focus of this thesis. Because of the focus on electric EE, lower electricity use resulting from fuel switching (e.g. changing electricity

---

[1] For replacement before end of equipment operational life, the counterfactual baseline is the energy use or peak demand of the equipment being replaced; for new instalment or replacement after end of equipment operational life, the baseline if the energy use or peak demand of equipment compliant with the product standards and/or industry common practice.

to gas) or distributed generation (e.g. rooftop solar photovoltaics behind meter) *does not* constitute electricity use reduction in this thesis. Furthermore, the counterfactual baseline is adjusted for exogenous conditions (e.g. weather, economic or production activities). For example, a lower electricity use purely because of slowing of the economy or a forced power cut *does not* constitute as electricity use reduction.

- Fourth, electricity use reduction is distinct from demand-side response (DSR)[2]. Although DSR requires customers to change their electricity use (e.g. reduction or shift of load), it is *temporary* in nature and responds to pricing or dispatch order made in accordance with the system operation (Section 2.5). By contrast, once electric EE measures are installed, the resultant electricity use reduction depends on the usage of affected equipment – it is permanent[3] and does not respond to pricing or system dispatch (i.e. non-dispatchable). However, given that electricity use reduction and DSR are often closely linked under the category of 'demand-side resources', Chapter 7 considers how a mechanism should look like in integrating demand-side resources in forward capacity auctions, while highlighting the difference between electricity use reduction and DSR as well as the implication for the design of integration mechanisms.

Table 1-1. Definition of key terms

Term and/or abbreviation	Definition
Electricity use reduction	Overall reduction in electricity use (in kWh) from a counterfactual baseline, adjusted for exogenous factors
Peak demand reduction or savings	Average reduction in electricity load (in kW) over system peak periods
Electric energy efficiency (EE) measures	Equipment/measures to achieve electricity use reduction for the same level of energy service
Demand side response (DSR)	Temporary changes in electricity load (in kW) by customers in response to pricing signals or system dispatch

---

[2] In this thesis, DR and DSR are used interchangeably

[3] After installation of electric EE measures, 'permanent' savings refer to savings without changing the usage patterns of affected electric equipment, which are non-dispatchable. However, measures' performance may decline over time, affecting the level of savings.

1.1. Research aims and questions

This thesis aims to examine the *role of the forward capacity market in promoting electricity use reduction*, which is inspired by the two objectives of EDR Pilot. It seeks to answer two research question:

1) Can the forward capacity market serve as a *primary* vehicle to give financial incentives to encourage electric EE and support electricity use reduction?
2) As one mechanism to ensure adequate capacity, can the forward capacity market promote electricity use reduction *as a capacity resource*?

To answer these research questions, two general strategies are taken. First, this thesis focuses on *central* design features and policy assumptions of using the forward capacity market to support electric EE. Its main interest is the high-level lessons for countries setting up a forward capacity market on its role in promoting electricity use reduction. In other words, it is about a *general* policy approach. Therefore, instead of focusing on every single detail in design, which may differ across jurisdictions depending on local conditions, this thesis concerns key aspects of the forward capacity markets. As discussed in Chapter 3, the methodological implication is the importance of cross-case analysis, particularly how the difference in key design relates to that in outcomes.

Second, a hypothesis-driven approach is used to further interpret research questions and make explicit assumptions or logic chains behind the policy design (Chapter 3). For the first question, if the hypothesis is that the forward capacity market can be a primary vehicle for incentivising electricity use reduction, it makes two broad assumptions.

> **Hypothesis 1: Financial incentive based on peak savings provides *comparable* financial support to energy savings of electric EE measures.** In other words, peak savings and energy savings are expected to be aligned (i.e. for the same amount of energy savings, little variation of peak savings across electric EE opportunities) to ensure *comparable strength* of financial

support, regardless of whether it is based on peak savings or energy savings. The alignment of peak- and energy-savings is important for two reasons. First, given that many customers do not yet face a time-differentiated retail tariff, customers considering electric EE investment would need to see that financial incentive based on project peak savings is most well aligned with that based on energy savings, which determine the payback. Second, if the objective of policy is to reduce overall electricity use, peak savings should be almost identical to energy savings (i.e. being aligned) for it to be logical to exclusively focus on the former to achieve policy impacts.

Hypothesis 2: A savings-based approach for giving financial incentives, as implied by the design of the forward capacity market, is *effective* for driving electric EE investment in *various* customer sectors. As further discussed in Chapter 5, integrating electricity use reduction in a forward capacity market represents a savings-based approach for giving financial incentives based on *verifiable* project peak savings[4], demonstrated in compliance with measurement and verification (M&V) protocols by project sponsors, not on choice of technology or measure, or size of investment. It is distinct from a traditional prescriptive approach in which incentives are given based on the choice of technology and it is the scheme administrator, not project sponsors, that bears the M&V responsibility and savings risk. If it is sufficient to rely on the forward capacity market as a primary vehicle, it should be able to promote participation from diverse customer segments and project types, effectively and with satisfactory outcomes. In other words, a savings-based approach and its designs may not create undue barriers for participants to offer projects and earn payment.

For the second question, if the hypothesis is that the forward capacity market can promote electricity use reduction as a capacity resource, the assumption would be:

---

[4] In accordance with M&V protocols, savings may be estimated based on well-developed parameters, metered or modelled, depending on the project nature and uncertainty of savings.

Hypothesis 3: Capacity products can be defined to value the contribution of electric EE projects towards capacity adequacy, and mechanisms designed to integrate electric EE resources in competitive capacity auctions and verify their capacity value. Electric EE contributes to the capacity adequacy by delivering non-dispatchable peak savings, which are distinct from dispatchable capacity from generation or temporary load changes of DSR. Given this, appropriate capacity products (e.g. definition and determination of peak savings, M&V requirements) need to be designed for electricity use reduction to offer as a type of commodity in the capacity auction. Moreover, the rules and requirements of capacity auctions should not pose undue barriers for organisations to offer electricity use reduction as a capacity resource, in competition against other resource types.

To assess these assumptions and hypotheses, this thesis draws upon theory and practice of evaluating EE policy, and utilises case studies and a mix of qualitative and quantitative methods (e.g. online survey, semi-structured interviews and document/dataset analysis) to synthesise from a combination of primary and secondary evidence.

1.2. Overall argument and structure of thesis

The argument of this thesis consists of two strands – the first strand is based on empirical papers in Chapters 4-6, while the second strand draws upon the paper in Chapter 7:

1. The forward capacity market can only play a minor role in advancing the policy objective of incentivising investment in electric EE measures;

2. However, it is a viable mechanism to reward capacity value of electricity use reduction, which requires appropriate definition of capacity product, regulatory support and removal of barriers for participation.

Chapter 2 reviews key background literature, including the value of electricity use reduction, barriers it faces and policies to address them, electricity market restructuring, an emerging interest in the capacity market as one solution to ensure resource adequacy, and the potential of demand-side resources in taking part in the wholesale electricity markets. Gaps in literature are highlighted.

Chapter 3 introduces some high-level methodological considers for this thesis overall, while the detailed methodology is discussed in each empirical paper.

Chapter 4 examines the relationship of peak demand reduction and energy savings by broad types of electric EE measures. It shows that peak- and energy-savings of electric EE measures are not necessarily aligned, and financial incentives based on peak savings are not comparable to that based on energy savings. In light of this, giving financial incentives solely based on peak savings may not capture a wide range of EE opportunities – in fact, it may only benefit a subset of them. It contributes to the analysis for Hypothesis 1.

Chapter 5 empirically analyses cases of savings-based incentive schemes in North America, the UK and Europe, and their benefits and limitations for promoting electricity use reduction. It finds that a savings-based approach is flexible to fit with diverse project and customer needs and can make valuable contributions in acquiring EE resources. However, this benefit is limited to non-residential sectors, and mostly customised projects or those above a certain size. It highlights the value of savings-based incentive schemes in complementing rather than replacing prescriptive schemes.

Chapter 6 focuses on the social housing sector in the UK, as a case study, for examining the potential of the EDR Pilot, and the forward capacity market in general, in promoting electricity use reduction in residential sector. It identifies barriers faced by the residential sector to utilise funding from the Pilot. While opportunities exist for electricity use reduction in lighting, appliances and heating, financial incentives based on the impact on system peak demand are unlikely to be attractive and disadvantage insulation and efficient heating system. Limited budget for electric efficiency project and inflexible requirement of over two-year payback of EDR Pilot poses the challenge of funding projects, especially for small organisations, even if they can deliver capacity value to the electricity system. The obligation to deliver and verify committed peak savings, and limited scope for payback present challenges and risks for projects to target potential opportunities within households. For communal electricity use, the minimum savings, cash-flow and limited internal capabilities are constraints. Thus, it is inadequate to rely on a forward capacity market as a primary vehicle for incentivising electric EE in households.

Together with Chapter 5, Chapter 6 contributes to the analysis for Hypothesis 2 and shows that while valuable, a savings-based approach for giving financial incentives may not be effective in capturing EE opportunities in *all* customer or project types, suggesting that it may not play a major role in incentivising the electric EE investment.

Chapter 7 undertakes case studies of ISO New England (ISO-NE), PJM and the EDR Pilot and the GB Capacity Market to examine the process and outcomes of procuring EE and DSR in the forward capacity markets, and policy lessons for the design of procurement mechanisms. It finds that the contribution of DR and EE varies wildly across these three capacity markets, due to a set of factors regarding mechanism design, market conditions and regulatory provisions, and the offering of EE is more heavily influenced by regulatory utility EE obligation. Requirements to ensure capacity adequacy and resources' market potential need to be considered in defining capacity products. In the long run, it is vital to remove the barriers for these demand-side resources and strengthen the capability of providers in addressing risks of unstable funding and forward planning. It supports the analysis for Hypothesis 3.

Chapter 8 synthesises key high-level findings and implications of thesis. It addresses the 'so what' aspects of the whole thesis, namely how each empirical paper contributes to the overarching argument, policy implication, future research opportunities and contribution to literature.

2 | Literature review

This chapter reviews the theoretical and policy background for electricity use reduction and capacity market. It starts with a brief overview of its benefits and approaches to promoting it. The policy context for promoting electricity use reduction in the UK is summarised. Then, the history of electricity market restructuring and the emerging interest in the capacity market for ensuring capacity adequacy is discussed. Finally, the status of demand-side resources participating in restructured electricity markets is reviewed.

2.1. Value of electricity use reduction

The power sector has a pivotal place in energy industries and electricity use reduction makes profound contributions on issues of climate change, energy security and economic efficiency.

2.1.1. Mitigating carbon emissions and air pollution

The electricity sector accounts for a large share of carbon emissions. For the world overall, electricity and heat contributed 42% of CO_2 emissions from fuel combustion in 2014, up from around 37% in 1990 (IEA, 2016a). In the US, the second largest-emitting country globally, power generation was responsible for 36% of energy-related CO2 emissions in 2015 (EIA, 2016). For the UK, electricity generation accounted for 26% of CO_2 emissions in 2015 (BEIS, 2016a).

Remarkable progress has been made in decarbonising the electricity supply. On a global level, the share of renewables (e.g. hydro, solar and wind) in the power and heat sector reached 20% in 2014, and capacity addition of renewables outpaced fossil fuels and nuclear for the first time in 2015 (IEA, 2016b). Even so, reducing overall electricity use is still a key lever for climate change mitigation. To limit the mean temperature increase to 2°C, the projections of International Energy Agency suggest that around 18Gt of additional energy-related carbon emissions reduction needs to be achieved beyond the projected reductions based on the Nationally Determined Contributions (NDCs) in 2040, with 60% of the additional reduction coming from power sector (IEA, 2016b). Of that, electricity use reduction would make roughly 25% contributions, placing it in an equally – if not more – important position as development of renewables and other low-carbon options including nuclear and carbon capture and storage (Fig. 2-1). Like carbon emissions, electricity use reduction can also help lower other air or water pollution from power generation (e.g. mercury, $PM_{2.5}$, SO_2 and NO_X), thus improving the ambient air quality and public health (e.g. EPA, 2013; Lamont and Gerhard, 2013).

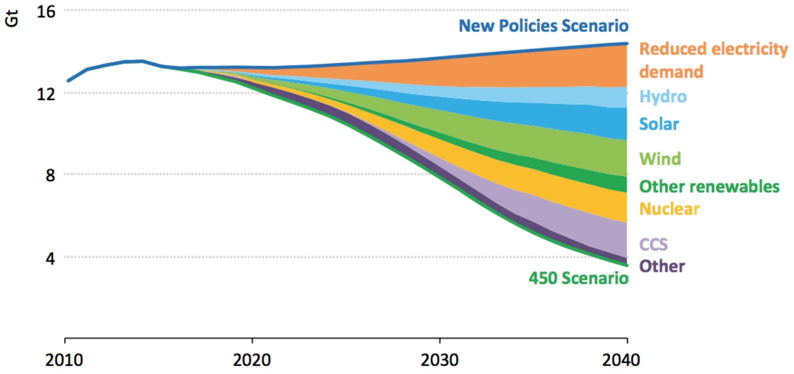


Fig. 2-1. Global CO2 emissions savings in the power sector in the 450 Scenario relative to the New Policies Scenario

Source: IEA (2016b)

Electricity use reduction during system peak hours, for each unit of energy saving, tends to deliver greater reduction in carbon emissions and air pollution. It is because peaking generation, which comes later in the ‘merit order’ and would be dispatched when system is in high demand, is likely to be less efficient and more polluting in many systems (e.g. Jamal, 2015).

2.1.2. Contributing to capacity adequacy

Electricity use reduction during peak hours, or *‘peak demand reduction’* as defined earlier in this thesis, provides an alternative to generation or network reinforcement for reliable, efficient system operation. For electricity systems, it is necessary to maintain adequate capacity to meet peak demand and reserve requirement to ensure supply security. Traditionally, growing peak demand, due to greater electricity use or penetration of specific end-uses (e.g. air conditioning in a summer-peaking system or heat pumps in a winter-peaking system), necessitates investment in generation capacity. Similarly, local network congestion caused by growing peak demand or more recently, concentrated deployment of distributed generation like solar photovoltaics (PVs) leads to network reinforcement needs. However, the relatively low load factor of marginal capacity in generation and transmission and distribution (T&D) suggests suboptimal asset utilisation and high cost for system operation. Moreover, in some cases, the practical difficulty in capacity expansion (e.g. social acceptability of T&D construction) underscores the value of alternative options.

By reducing peak demand, through installation of efficient electrical equipment, it can lower capacity needs and improve the overall asset utilisation (Kushler et al., 2002; Kushler and Witte, 2003; Nadel et al., 2000). As further discussed in Section 3 of Chapter 4, the cost of energy saving through EE measures tends to be a small fraction of that of electricity supply (e.g. Kushler et al., 2012; Molina, 2014; NAPEE, 2008). For meeting capacity needs, there is evidence that electricity use reduction can be more cost-effective than generation capacity or network reinforcement (e.g. Anthony and Foley, 2014; Gottstein and Schwartz, 2010; Neme and Sedano, 2012).

Moreover, compared with generation, electricity use reduction has lower risk. This is because of the 'diversification' effect of EE portfolio – that is, EE resources comprise of many discrete small units that are unlikely to 'fail all at once' – and the 'short lead-time' and scalability of installing EE measures, which lowers the risk of project overrun and helps buy more time for assessing the need to add generation capacity (Lazar and Colburn, 2013; Neme and Sedano, 2012).

In the U.S., utilities and system operators have a long tradition of deploying EE resources to promote capacity adequacy. During the 1970s, the practice of *'least-cost planning'* emerged that alternatives to new power plants should be utilised to meet the needs of energy services 'at lower cost' (Eto, 1996). It was in response to upward pressures on electricity bills, due to factors like rising prices of oil and gas, and enactment of stringent air pollution laws that increase costs of new power plants – in fact, the regulation on utilities' investment was tightened, with regulators limiting the amount of investment that could be recovered from new nuclear projects. Although in the past utilities would build capacity and subsequently seek regulatory approval for investment recovery, the least-cost planning means that utilities' resource acquisition needs to be approved by regulators before new capacity is built (Goldman et al., 1989; Schweitzer et al., 1991). As part of it, integrated resource planning (IRP) needs to consider cost-effective demand-side resources like EE and DSR (e.g. demand-side management, or DSM) in a similar way as generation (Eto, 1996). As seen in Lamont and Gerhard (2013), the process of IRP may vary between states, from equal treatment of demand-side and supply solutions in resource planning, to integration of DSM plans developed in a separate process in the IRP process.

The subsequent market restructuring has weakened the institutional and financial basis for IRP and DSM; however, concerns of system reliability, rising costs and environmental impacts have re-centred efforts to acquire demand-side resources since early this century (Barbose et al., 2013). Energy Efficiency Resource Standards (EERS), which oblige utilities to achieve specific energy- and/or peak-saving targets, have been established in half of the states in the U.S. (Downs and Cui, 2014; Gilleo et al., 2015a; Kushler et al., 2006; Palmer et al., 2013b). In some regions, market restructuring transferred the responsibility of promoting capacity adequacy to system operators – some of them have resorted to forward capacity markets to procure resources, with a few allowing the participation of EE and DSR resources (Section 2.4).

In Europe, the focus has been on the potential of EE to achieve energy savings and carbon emissions reduction (Rosenow and Galvin, 2013). However, the concern of capacity adequacy emerged recently, due to several market and regulatory factors (EC, 2016b). First, the growing penetration of renewables with low short-run marginal cost, together with decline in electricity demand due to economic reasons, has led to a notable drop in the utilisation of thermal generation capacity. Moreover, depressed wholesale price – due to the combined effects of lower demand

and carbon price, and pick-up of coal in the fuel mix due to its lower price thanks to the shale gas development in the U.S. – hit the revenues of thermal generation, especially flexible capacity like closed-cycle gas turbine (CCGT). While the EU overall has generation overcapacity, there is a concern that due to such structural factors, such downward pressure on generation would persist, leading to large-scale retirement, particularly of flexible capacity (e.g. CCGT) that is needed for balancing intermittent renewables. Second, in some member countries, the concern of capacity inadequacy is more acute – this would be amplified by planned retirement in the near term due to stringent environmental regulation, operational lifetime and national energy policies (EC, 2016a). In the UK, the tightening margin of generation capacity, resulting from planned closure of coal power plants because of emissions regulation, has brought the issue of capacity adequacy into policy spotlight (DECC, 2014d). Moreover, some local networks begin to see congestion in areas with concentrated penetration of heat pumps and solar PVs (UKPN, 2014b).

With the agenda of capacity adequacy and system flexibility for integrating renewables, the debate in Europe puts utilising demand-side resources at a central place. While it focuses on DSR and storage, there is an emerging interest in the potential of electricity use reduction as a capacity resource. In the UK, the EDR Pilot remunerates EE investment for its impact on system peak demand (Section 1.1). In exploring alternatives to reinforcement to address the constraint on local networks, the benefits of electric EE and DSR are highlighted by distribution network operators (UKPN, 2014a, c). As per the analysis of UK Power Networks, a distribution network operator in London, significant potential exists for reducing winter peak demand on low-voltage networks from efficient lighting (15%) and to a less extent, cold (3%, e.g. refrigerators) and wet (2%, e.g. washing machines) appliances.

2.1.3. Accruing benefits to end-use customers and the society

For customers taking up electric EE measures, lower energy use would translate into savings on energy bills. Economic savings from using electricity use reduction to substitute capacity needs in generation and T&D would accrue to the whole customer population as reduced capacity and network charges (Lazar and Colburn, 2013). Moreover, electricity use reduction may also lower wholesale market price, which may have contagion effects on related energy markets (e.g. natural gas), thus benefiting customers. For low-income households, who tend to see energy bills as a significant part of monthly expenses, the relative impacts of lower energy bills would be greater.

In a broader sense, investing in EE measures may also have wider, non-energy socioeconomic benefits (IEA, 2014a). For low-income households, insulation measures (e.g. insulation, efficient windows) would improve heating quality and comfort level, thus alleviating negative health consequences of under-heating (Boardman, 2012b). For commercial buildings, efficient lighting, with improved lighting quality (e.g. reduced glare on computer monitors), may help improve productivity of employees. Moreover, there is some evidence that investment in EE measures and development of the industry can have wider economic benefits, including job creations and energy security (Blyth et al., 2014; IEA, 2014a).

2.2. Approaches to promoting electricity use reduction

This section reviews the theoretical background of barriers for investment in EE measures, and why policy interventions are often necessary. It describes some common policy options for promoting the electric EE investment, of which a financial incentive is a key part.

2.2.1. Theories of barriers for investment in EE measures

Energy use reduction can come from two general areas: 1) investment in improved EE and 2) conservation or lower demand for energy services. EE is a ratio of useful outputs to energy inputs – while useful outputs can be defined in different terms (e.g. converted energy or value-added), in many cases, energy service is conceptualised as a useful output (Sorrell, 2015). For the same level of energy service, higher EE means lower energy inputs. Measures to improve EE are specific to end-uses, ranging from investment in lighting and appliance of higher energy ratings, insulation to more efficient industrial processes. Although there is abundant literature on ‘rebound effects’, i.e. higher demand for the same or other energy services because of higher cost-efficiency associated with improved EE, evidence exists that they tend to cancel out only a part, if at all, of energy use reduction by improved EE (Gillingham et al., 2013; Greening et al., 2000). Moreover, a reduced need of energy services, due to behavioural change or economic activities, also has the potential to reduce energy use.

There is established literature that market barriers may exist for investment in improved EE, which suggests the need of policy intervention to promote socially efficient outcome (Golove and Eto, 1996). Many studies have estimated high potential for efficiency improvement that are cost-effective but not taken up by the market (Sorrell, 2015). That said, there is an ‘efficiency gap’, referring to the difference between cost-effective efficiency improvement potential and what is occurring (Golove and Eto, 1996). Orthodox economics assuming individual rationality based on purely economic cost-benefit analysis is not sufficient to explain the ‘efficiency gap’ – the implicit discount rate suggested by the ‘gap’ of EE investment is higher than other investment based on the market price. If a social discount rate is used (i.e. accounting for externalities), the ‘efficiency gap’ would be larger (Fig. 2-2). This led to the argument that several market barriers prevent EE improvement from being taken up in the market as predicted by economic theories (Blumstein et al., 1980).

Theory of market barriers for EE has developed over time. While it initially focused on neo-classical economics, perspectives from alternative disciplines (e.g. transaction cost economics, behavioural economics, decision theory, organisational theory) have strengthened the explanation for the ‘efficiency gap’ – in fact, they are complementary with each other, as opposed to being mutually exclusive. A comprehensive review of how various theories frame and explain the issue can be found in Sorrell et al. (2000). Thus, to avoid ‘recreating the wheel’, only a short synopsis is provided here.

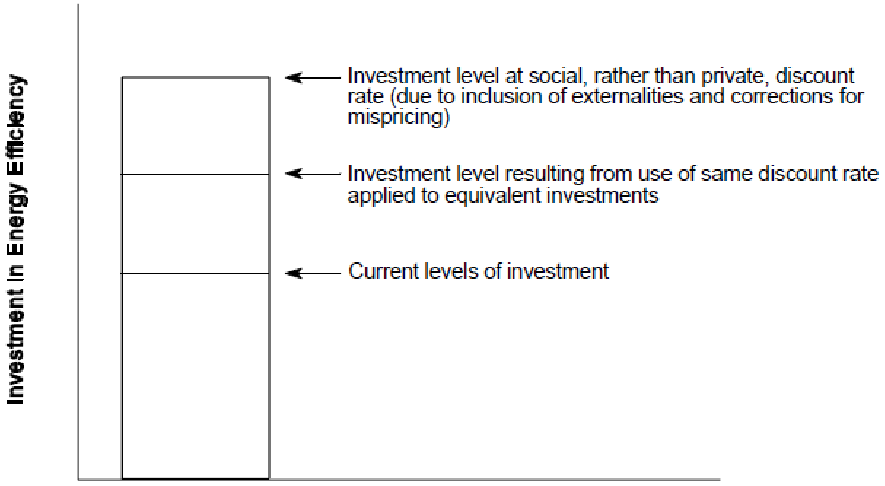


Fig. 2-2. Schematic illustration of 'energy efficiency gap'

Source: Golove and Eto (1996)

a) Economic perspectives

The core assumption of neo-classical perspectives is that individuals are rational, or acting *as if* they are (Sanstad and Howarth, 1994). Thus, whether to invest in EE or not is a matter of rational assessment of costs and benefits of doing so. In other words, the 'efficiency gap' is due to barriers that lead costs of EE improvement to exceed benefits. Blumstein et al. (1980) is a seminal work characterising these barriers, namely split incentives, lack of access to capital, market structure barriers inhibiting penetration of EE measures, utility regulation leading to an energy price that does not reflect marginal cost and inseparability of EE from other features of a product (i.e. 'gold plating'). Other barriers were later added to the list, including hidden cost of EE improvement (e.g. management time, disruption), cost-benefit heterogeneity among adopters (Golove and Eto, 1996) and risks (e.g. market, business and technical risks) (Hirst and Brown, 1990; Sorrell et al., 2000). However, some of these barriers like access to capital and hidden costs were criticised by neo-classical economists as reflecting the functioning of markets (Sorrell et al., 2000). In fact, it is argued that economic efficiency, not necessarily EE, should be the aim of public policy that is only justified if barriers constitute *market failures*, which prevent the market from efficiently allocating resources (Golove and Eto, 1996; Jaffe and Stavins, 1994; Sutherland, 1996). However, this argument is debatable since barriers not classified as market failures in Jaffe and Stavins (1994) may need to be addressed for political and policy aims other than economic efficiency (e.g. equity, climate change) (Sorrell et al., 2000). Two types of market failures can help explain the 'efficiency gap': 1) imperfect information in market about energy performance of technologies, e.g. availability, cost and accuracy of information (Eyre, 1997; Golove and Eto, 1996; Hewett, 1998); and 2) asymmetric information in market, e.g. adverse selection where difficulty of buyers in obtaining information makes them hesitant to pay for EE investment (Howarth and Sanstad, 1995), principal-agent relationship (e.g. building designer and future client occupants) and split incentive (e.g. landlord and tenants).

Neo-classical perspectives tend to see market players as 'unitary, profit maximising actors' – it is inadequate for understanding the behaviours of individual organisations (Sorrell et al., 2000). In this context, organisational economics that draw upon economic concepts (e.g. moral hazard, asymmetric information, transaction costs like cost of gathering and assessing information) to explain the behaviour of individual organisations (Gifford, 1994; Rowlinson and Procter, 1997) complement neo-classical economics. *Organisational failures* can result from internal structure, procedure and incentive, and prevent organisations from acting as assumed by neo-classical economics. Examples include principal-agent relationship and split incentive within organisation. As argued in Sorrell et al. (2000), policies to address organisational failures like asymmetric information and high transaction costs can be justified if they prove cost-effective.

b) Behavioural perspectives

Regardless of its usefulness for explaining some barriers for EE improvement, neo-classical economics is criticised of its core assumption of individual rationality being not representative of the real-world behaviours, thus being inadequate in explaining the 'efficiency gap' (Kempton and Montgomery, 1982). Two concepts from behavioural perspectives are helpful. First, *bounded* *rationality* recognises that individual decisions are constrained by resources, time and cognitive capabilities, and that consequently individuals tend to use 'imprecise routines and rules of thumb' and seek 'satisfactory decisions' rather than aiming for optimisation (March, 1978; Simon, 1966). In an organisational context, payback rules for investment (e.g. hurdle rates), budgeting and procedures for operation, maintenance and equipment replacement are examples of such rules of thumb or routines (Sorrell et al., 2000). Second, from social psychology, the form of information (e.g. whether information is specific, clear and conducive to feedback), credibility of source and trust (Craig and McCann, 1978; Stern, 1986), and inertia for making improvements (e.g. undervaluation of opportunity costs, uncertainty about potential savings, and preference for regret minimisation) may create barriers for EE investment, while values can be an important variable as well (Sorrell et al., 2000).

c) *Organisational perspectives*

Different from organisational economics applying economic concepts to explain behaviour of organisations, organisational theory is 'diverse and eclectic', drawing upon various disciplinary perspectives to characterise the behaviour of organisations (Rowlinson and Procter, 1997). As noted in Sorrell et al. (2000), at least three concepts from the organisational theory are relevant to the EE improvement, even if they are not necessarily barriers. First, the organisational structure influences access to information and power and resources of individual actors in an organisation to assess and invest in opportunity for EE improvement (Cebon, 1992). Second, borrowed from political science, the idea of power can be relevant to EE investment in the sense that status, resources and incentives of individuals or teams tend to be important variables for their ability to influence decisions relevant to energy issues (DeCanio, 1993, 1998; Sorrell et al., 2000). Third, the culture within an organisation, characterised by 'knowledge, ideology, values, norms, laws and day-to-day rituals', may also influence the adoption of EE measures (Sorrell et al., 2000).

d) *Innovation perspectives*

For novel EE measures (e.g. heat pump, solid wall insulation), policy support is justified for their development and market diffusion from the perspectives of innovation theory (Sorrell, 2015). It is mainly because new technologies tend to be more expensive, lack established supply chains (e.g. engineers and contractors with relevant expertise, distribution channels), require changes in user practices and have public benefits that are not necessarily captured by early users (Sorrell, 2015).

2.2.2. Common policy options for promoting investment in electrical EE measures

To address these above barriers for EE improvement, a mix of policies with different designs, institutional set-up and implementation are created. Following the classification in Rosenow et al. (2016a), these policies of heterogeneous designs can be broadly grouped into six categories with each of them aiming to address slightly different barriers:

- **Financial incentives** or purchase subsidy to reduce upfront investment of EE (e.g. grants, retail or tax rebates, upstream buy-down), improving the economic case and payback for installing more efficient equipment (e.g. lighting or motors) and undertaking changes that can affect energy use (e.g. building insulation, industrial processes);

- **Support for financing** or access to capital (e.g. preferential loans or on-bill financing) to improve the availability and/or cost of financing EE investment;

- **Standards and norms** (e.g. building codes, performance requirements for processes) for measuring the efficiency levels of products, services and buildings;

- **Minimum requirements for EE** (e.g. regulation or voluntary agreement on EE standards for products and buildings) to set legal or self-imposed requirements to increase market penetration of products or buildings with higher efficiency ratings;

- **Information and feedback** (e.g. energy labelling for products or buildings, feedback to customers via energy bills and other media, smart metering, information and advice) for addressing imperfect information barrier and informing purchase decision-making; and
- **Taxation for energy or carbon emissions** (e.g. carbon price) to internalise external costs of energy supply and consumption to promote socially efficient level of energy use, if the demand adequately responds to pricing signals.

Other policy designs allowable under the Article 7 of Energy Efficiency Directive of EU may include energy efficiency national fund, and training and educational programmes for professions related to EE improvement such as auditors and energy managers (EC, 2013).

Policies are rarely implemented in isolation (e.g. Doris et al., 2009; Nadel et al., 2015). This implies a complex landscape of EE policies and a need for understanding their interactions to the extent that they influence the outcomes for policy objectives (Eyre et al., 2015; Geller and Nadel, 1994; Lee and Yik, 2004; Swisher, 1996). Rosenow et al. (2016a) is a seminal research on this, arguing that theoretically, information and feedback together with carbon price can complement other policies, while financial incentives and support for access to capital for the same technology or sector may overlap. As for regulatory measures such as product standards, the relationship with financial incentives is more complementary. On one hand, product and building regulations have the potential of achieving large cost-efficient energy- and peak-savings, and are indispensable for the policy efforts in doing so (e.g. Boardman, 2012a, 2014; Molenbroek et al., 2015). On the other, regulatory measures may have limitations such as compliance issues, slow equipment turnover or institutional inertia to keep up with technological innovation (Cary and Benton, 2012). Financial incentives are helpful in addressing some of the limitations, by strengthening the market pull of more efficient products and buildings (e.g. Boardman, 2012a; Green Alliance, 2012). Section 2.3 summarises key policies for promoting electricity use reduction in the UK.

In the policy mix, financial incentives play a salient role, which can be seen theoretically and empirically. First, financial incentives lower up-front cost of EE improvement, which is identified as a key barrier for the uptake of efficient equipment (de la Rue du Can et al., 2014; Hausman, 1979; Houston, 1983). By improving the payback, financial incentives are believed to alleviate the split incentive and help EE project pass the hurdle rate, while the availability of financial support itself may raise the salience of EE in an organisation (DECC, 2012). Incentive schemes may also support the market development for EE measures (de la Rue du Can et al., 2014) or even the market transformation (Nadel and Latham, 1998; Rosenberg and Hoefgen, 2009). Second, for promoting the building efficiency in 14 EU countries, an empirical analysis shows that financial incentives (e.g. grants, utility energy efficiency obligation, rebates) are the most common policy, which typically are combined with other policy instruments (Rosenow et al., 2016a). In the US, more than half of the total expenditure of utility EE obligation programmes was spent on customer incentives and rebates over 2011-15 in New York and states served by ISO-NE, with many of them topping the league table of the American Council of an Energy-Efficient Economy (e.g. Massachusetts, Vermont) (NEEP, 2016).

Nevertheless, while the literature reports on financial incentive schemes for EE improvement (e.g. Geller and Attali, 2005; Hilke and Ryan, 2012), there lacks a comprehensive analysis or synthesis of specific scheme design features (de la Rue du Can et al., 2014). Scheme design has important implications for achieving ambitious saving targets (York et al., 2013). One key area is how specific participation processes, requirements and rules would affect the ‘customer journey’ of obtaining financial incentives, and how this implies for quantifiable policy impacts like energy savings or cost effectiveness. While some high-level design considerations (e.g. funding source, interaction with standards and labelling scheme, target of incentive) are discussed in de la Rue du Can et al. (2014), many key issues remain largely unaddressed, particularly how to structure the incentive and the approach for providing it.

As discussed in Chapter 1, this thesis focuses on an innovative design for providing financial incentives, i.e. a savings-based approach modelled after the forward capacity market. In the case of EDR Pilot, it is seen largely as a 'catch-all' approach for incentivising EE investment in the UK (DECC, 2013a). Considering this, this thesis can make contributions in at least two aspects. First, understanding how customers respond to this innovative design of incentive schemes would contribute to the literature and policy debate of how incentive schemes should be designed. As discussed later, scheme evaluation, especially process evaluation, is useful that it opens the 'black box' of implementation and allows scrutiny of how scheme outcomes relate to specific design features. Second, given that the forward capacity market is established or being contemplated in many jurisdictions, this thesis contributes to the knowledge of whether allowing electricity use reduction to offer as a capacity product would be sufficient for encouraging electric EE. Such an understanding of the role the forward capacity market can play helps to inform the policymaking in terms of whether additional regulatory provisions would be necessary.

2.3. Policy context for electricity use reduction in the UK

This section summarises the policy landscape for encouraging measures that can realise electricity use reduction in the UK, given the focus of this thesis on the EDR Pilot and its design. Various national and EU-level regulatory provisions and policy schemes are in place, addressing different barriers of taking up EE measures. As seen below, financial incentives for EE to promote electricity use reduction are limited in the residential and commercial and industrial (C&I) sectors. DECC (2012) provides a summary of these policies.

2.3.1. Residential sector

The energy supplier obligation is the main programme providing financial incentives to EE measures (e.g. insulation) in households of the UK. It is a principal policy instrument for driving EE investment (Rosenow, 2012). Over the two decades since it was first introduced, it has evolved greatly, with a reduced support for measures conducive to electricity use reduction. It can be seen in two aspects, which are further discussed in Chapter 6. First, for the Carbon Emission Reduction Target (CERT), efficient lighting and appliances made notable contributions to the total carbon savings, although financial incentives for such measures were discontinued in the later part of CERT (Rosenow, 2012; Rosenow and Eyre, 2015). Second, the policy ambitions are much diluted, leading to reduced activities of insulation installation, which the Energy Company Obligation (i.e. the supplier obligation succeeding CERT) ends up focusing on, while the incentive for insulation in electrically heated properties is strengthened. A detailed summary of how the energy supplier obligation has changed and why is provided in other studies (Mallaburn and Eyre, 2014; Rosenow, 2012; Rosenow and Eyre, 2015; Rosenow and Eyre, 2016).

Another financial incentive scheme for households is the Domestic Renewable Heat Incentive (RHI, 2014 onward), which replaced the Renewable Heat Premium Payment (RHPP, 2011-2014), for installing heat pumps, biomass boilers and solar thermal. For electrically heated households, it is possible to reduce electricity use with heat pumps that have a higher efficiency level than a typical electric heating (e.g. storage heaters) and fuel switching to non-electric sources (e.g. solar and biomass). Domestic RHI seems to be somewhat successful on this – over 2014-January 2017, 22% of the accredited installations replaced electric heating (BEIS, 2017b), a share higher than that of electrically heated homes in the UK (Chapter 6). However, if electricity is not the main heating source, switching to heat pumps is to increase electricity use. This appears to be the trend. Under the RHPP, heat pumps made up 60% of the installations; for the Domestic RHI (2014-January 2017), the share in the accredited new installations is 56% (BEIS, 2017b; DECC, 2015b). For the latter, 73% of heat pump installations occurred in non-electrically heated properties.

Regarding non-financial incentive policy provisions, smart meters are being introduced with in-home displays in a roll-out led by suppliers (i.e. Smart Metering Implementation Programme). It aims to enhance energy feedback to customers and enable opportunities for DSR (Darby et al., 2015), as well as delivering other benefits like cost savings in meter reading and easier supplier switch. Apart from energy labelling for products, the EU and the UK government set minimum

EE standards of products and buildings, under the Ecodesign Framework Directive (Boardman, 2004a) and Building Regulations Part L. The Decent Homes Standard required local authorities and housing associations to achieve a minimum efficiency level for their social housing properties.

2.3.2. C&I sectors

There is no coverage of the energy supplier obligation in non-residential sectors. However, some financial incentive schemes provide weak support for specific technologies or customer segments. One example is the Enhanced Capital Allowance that allows businesses and industrial customers to write off 100% of capital cost of eligible energy-saving equipment[5] against taxable profits. The CRC Energy Efficiency Scheme requires large public and private organisations (i.e. using >6,000 MWh per year and having at least one half-hourly meter settled on the wholesale energy market) to report and purchase allowances for CO_2 emissions. The Climate Change Levy is a form of energy tax on C&I customers, and energy-intensive industries can strike Climate Change Agreements to improve their EE levels in return for a discount on the Climate Change Levy. However, as noted in Rosenow and Eyre (2015), the CRC Energy Efficiency Scheme and the Climate Change Levy are ‘blunt instrument(s)’ and additional policy provisions are needed. After 2018-19, the CRC Energy Efficiency Scheme is to close and be replaced with an increase in the Climate Change Levy.

For non-financial incentive policy provisions, Salix Finance provides zero-interest financing for EE investment and Energy Savings Opportunity Scheme (ESOS) requires large organisations to conduct audits every four years. Although the Ecodesign and energy labelling primarily cover residential products, there is a scope for including more commercial products in the future. In fact, the EU ENERGY STAR programme is a voluntary agreement between the EU and the U.S. to co-ordinate energy labelling of office computing equipment.

---

[5] Based on the Energy Technology Product List as updated and managed by the government

2.3.3. Need for additional financial incentives for encouraging electricity use reduction

A conservative estimate shows a large potential for electricity use reduction (~32TWh/year or 9% of the projected electricity use in 2030) by improving EE of electrical equipment, appliance and processes (DECC, 2013b; Eyre, 2013b). In a government consultation, it was postulated that to capture the potential, additional financial incentives are needed to enhance the payback of EE investment and alleviate barriers like split incentives and bounded rationality (DECC, 2012). This led to a discussion on how this financial incentive scheme is to be designed, while the EDR Pilot that tests whether EE can be adequately incentivised by the GB Capacity Market was adopted in the end (Chapter 1). Regardless, it is widely recognised that non-financial provision (e.g. product labelling, feedback, information access, mandatory energy audits for large non-residential users, loans) would be essential and should complement financial incentives (DECC, 2012, 2013a).

2.4. Electricity market restructuring and capacity market: background and experience

The electricity industry in many countries has undergone substantial structural changes in the last three decades. A wave of reforms, intended to introduce competition in an industry traditionally vertically integrated and a monopoly, started in Chile and the UK in the late 1980s. Ever since then, many other countries have reformed their power sectors, although to varying degrees. This grand experiment has changed the way the industry is organised and the paradigm of system planning and operation. It has produced benefits but also comes to face new challenges, such as ensuring adequacy of capacity resources, especially against the backdrop of low-carbon energy transition. At the same time, promoting the participation of demand-side resources, as a potential solution to these challenges, is a policy agenda gaining momentum in the restructured markets. This section reviews the experience of electricity market restructuring at a high level, with a focus on the implication for long-term capacity adequacy and policy responses to support it, while Section 2.5 summarises the status of demand-side participation in restructured electricity markets.

The term *reform* is used broadly to mean changes in the structure, regulatory framework and/or market design. Across countries that have reformed their electricity sectors, different types of changes have been implemented (Sioshansi, 2006a):

- **Restructuring** aims to re-organise the roles of market players or sectoral structure, or redefine regulatory rules and market design/structure;
- **Liberalisation** means introducing competition to segments of industry, while trying to remove barriers to competitive new entrants and trade/exchange;
- **Privatisation** refers to sales of publically owned assets to private firms or entities; and
- **Deregulation** involves removing or reducing regulation of market players (e.g. price regulation), and usually subjecting them to market-monitoring authorities (e.g. monitoring anti-competitive behaviours). It should be noted that reforms typically take place in 'a context of regulation' not without it, or in the form of 're-regulation' (Pollitt, 2008). One such regulation is the reliability requirement based on engineering standards as well as assessment on the acceptable level of supply reliability. Another example is the obligation of investor-owned utilities to promote energy efficiency at customers' end[6].

2.4.1. Vertical integration to market restructuring: why?

Before the market restructuring, as is still the case in many countries, electricity system and its segments of value chain (i.e. generation, T&D and retail) were usually vertically integrated[7]

---

[6] In the example of the U.S., investor-owned utilities are regulated by state regulators, while publicly-owned utilities (e.g. municipal utilities) are overseen by municipal governments, federal regulators or cooperative boards. However, many publicly-owned utilities also choose to undertake customer energy efficiency programmes.

[7] In the England and Wales, for example, before the restructuring, the electricity industry was under state ownership, with the Central Electricity Generation Board responsible for generation and transmission and 12 Area Boards for distribution and retail. In Scotland, the North of Scotland Hydro-Electric Board and the South of Scotland Electricity Board were two vertically-integrated regional franchises.

(Sioshansi, 2006a). Governments may own monopoly electric utilities and for some countries (e.g. the U.S. for urban areas, Japan), investor-owned utilities are the main providers as regional franchises – they operate as monopolies and are regulated by public regulators in areas like pricing, conditions and quality of retail service (Bonbright, 1961). Customers typically face regulated tariffs, which are periodically revised, to allow utilities to recover investment (Sioshansi, 2006a). Therefore, it is a regulatory framework based on 'cost-of-service' and amortisation of capital investment (Chao et al., 2008). The decision-making for operation and investment planning is integrated. Risks are pooled or 'socialised' along the supply value chain (e.g. buffering wholesale price volatility as a single utility, 'cost-of-service' to recover investment), although customers bear the residual risks including technology performance, construction and ramifications of possible changes in supply and demand (Joskow, 1997; Sioshansi, 2006a).

Several arguments are made in favour of a vertical integration structure. In economic theories, T&D networks are natural monopolies integral to the reliability of whole system. As it would be wasteful to duplicate them, the focus should be on regulating the quality and cost of their services (Chao et al., 2008; Sioshansi, 2006b). The argument is extended to generation. Large sunk costs of generation like coal, hydro and nuclear mean that investment are more viable with parties in a strong market position, and economics of scale can be achieved with large-scale projects (Chao et al., 2008; Michaels, 2004). Other benefits include economies of scope (i.e. cost synergies in sharing standards, skills and technologies like metering and IT) and less reliance on contracts, which are seen as insufficient to manage *all* risks associated with generation (Chao et al., 2008). Moreover, the need to coordinate generation and T&D, and to capture their 'complementarities'[8] is another prevailing reason for vertical integration (Joskow, 1997). For the regulated monopolies, the 'cost-of-service' rate regulation model guarantees recovery of investment and enables utilities to raise private capital at a low cost (Chao et al., 2008).

---

[8] Different from 'switched' networks like telecom, electricity system is unique that a failure in one part could have system-wide consequences. Therefore, electricity transmission system requires a complex coordination of generation and demand.

However, in the late 20th century, a few forces began to drive the trend of reform. While the exact motivations vary across countries, there are some common themes:

- **Inefficiencies of the regulated vertical integration model emerged.** First, its ‘cost-of-service’ model was seen as not giving sufficient incentives to utilities for optimising costs but rather creating perverse incentives for capital-intensive projects (e.g. Chao et al., 2008; Johnson, 1973). In some developed economies, in the late 20th century when power demand growth slowed, the industry came to face the issue of ‘substantial overcapacity’ (Stridbaek, 2005). The reason is two-fold – the bias towards secure supply (Sioshansi and Pfaffenberger, 2006a) and separation of investment decisions by utilities from cost- and risk-bearing by customers (Stridbaek, 2005). In the US, before restructuring in some areas, wide variation had been seen in the costs and speed of generation construction, and unit operating performance, thus underscoring the potential for system efficiency improvement (Joskow, 1997; Joskow and Rose, 1985; Joskow and Schmalensee, 1987). Second, it does not reflect current market value and conditions of generation, by locking customers into the amortised cost of generation for a number of years (Joskow, 1997). Before the reform, regulated retail prices varied wildly across the U.S., with a large part of such a variance due to difference in ‘sunk costs of generation investments’ (e.g. nuclear power plants in the northeast and California vs. low-cost coal and hydro in Indiana and Oregon) and long-term energy purchase contracts made during the 1970s and 1980s (Joskow, 1997). As noted in White (1996), the generation component of the regulated price was notably higher than the price in unregulated wholesale generation markets, because of excess capacity and development of cheaper CCGT in the latter. These were the primary drivers for market restructuring in the U.S. Efforts were concentrated in states with high regulated prices and led by large industrial customers who could benefit from low prices and new market entrants like independent power providers (Joskow, 1996; White, 1996). Third, the regulatory paradigm has only limited scope for utilising demand-side resources, even if they prove to be more cost-effective (Stridbaek, 2005). In the U.S., although DSM was first introduced under a vertical integration structure in the late 1970s and 1980s (Cappers et al., 2010; Hurley et al., 2013), its rate-setting practice is one barrier. In general, expenses of DSM are not large enough to trigger a rate case for retail price adjustment and do not create tangible assets on utilities' balance book, barring them from earning a return and creating disincentive for DSM (Hedman and Steiner, 2013). Even if special provisions are made (e.g. bill surcharge for DSM or treating DSM costs as revenue requirement in the rate case), vertical integration does not allow dynamic participation of demand-side resources to support system operation (Stridbaek, 2005). Finally, other drawbacks include lack of customer choice, cross-subsidy across customer classes and sub-optimal regulation (Sioshansi, 2006a).

- **The value of competition and markets to drive efficiency was gradually accepted.** This changed the perception of operating models and public ownership in many countries (e.g. Sioshansi, 2006a; Sioshansi and Pfaffenberger, 2006a). Competition in generation and retail, and pricing signals from wholesale market are assumed to reflect the 'efficient economic cost of supplying electricity' and provide incentives for controlling investment and operating costs of generation (Joskow, 2008b). Customers would benefit from 'lower electricity costs and improved services' (Sioshansi, 2008b). These gains stem from pressure for cost optimisation and operational efficiency for existing generation, choice of cheaper technologies, price transparency and allocation of investment risk to private investors rather than customers (Pollitt, 2008; Sioshansi, 2008b). Other benefits would be diverse customer options in the retail market for their needs and risk-bearing capabilities, and support for innovation (Joskow, 2008b). In the European Union (EU), market liberalisation is a process driven by the EU Electricity Market Directives to establish an Internal Electricity Market, and introduce competition and facilitate cross-border trading (Jamasb and Pollitt, 2005; Meeus et al., 2005). The Directives of 1996 and

2003 required member states to open electricity markets, guarantee third-party grid access and establish a separate system operator, with the second directive mandating a faster timetable and specific approaches to reform (e.g. legal unbundling of T&D, regulated T&D access).

- **Technological innovations were enablers.** Examples include smaller-sized and/or more cost-effective generation (e.g. CCGT) and development of systems to enable competition and transaction settlement, which weakened the economies of scale argument for vertical integration and increased 'feasibility of creating competitive generation market quickly' (Joskow, 1997; Sioshansi and Pfaffenberger, 2006a; Stridbaek, 2005). As the barriers to entry lowered for private investors in the generation market, pressure grew for opening the market to new entrants.

- **Market reforms were regarded as conducive to other policy benefits.** As discussed in Sioshansi (2006a), for developed economies (e.g. some parts of the US and Australia), other motivations for market restructuring include regulatory complexity, relief of public finances by privatising state-owned assets in power sector, and encouragement of cross-border trade. For some developing countries (e.g. China and India), motivations include the value of decentralised decision-making for system management, and the potential of attracting private capital to drive investment to alleviate power shortage.

2.4.2. Market restructuring and liberalisation: how?

Market restructuring and liberalisation, coupled with privatisation in some places, introduces many fundamental changes in practices of planning, operation and dispatch, how incentives are given and decisions are made, and customer engagement. There are two noteworthy points:

- **Electricity market reforms take widely different forms across countries**, in terms of industry structure, ownership, extent and pace of reform, market design and regulatory framework (Pollitt, 1999), while ‘blueprints’ for reform were proposed (e.g. Hunt, 2002; Joskow, 2003a; Joskow, 2008b; Newbery, 2002). As noted in Pollitt (2008) and CorreljÉ and De Vries (2008), the form and extent of reform is a choice, influenced by institutional factors, structure of industry and political economy in specific countries.

- **Reform is an ongoing complex process rather than a defined endpoint.** In most cases, market forms have given rise to new issues, necessitating re-design or policy refinement – it is characterised as ‘reform of the reforms’ (Joskow, 2006a). Sometimes, unintended consequences post-reform (e.g. price hikes, power shortages[9], social effects or governance issues) that may or may not be attributable to market restructuring led to stalled reform efforts. In contrast, the centrally-driven effort of the EU for an Internal Electricity Market is one of the main forces of market reforms, while China has recently launched another round of reforms to introduce competition to the electricity sector (Jamasb and Pollitt, 2005; Liu and Kong, 2016; Meeus et al., 2005).

Here common features of reform initiatives are summarised, for the transition to competition and liberalisation. Detailed country-specific cases can be found in Sioshansi and Pfaffenberger (2006b) and Sioshansi (2008a, 2013).

- **Structural unbundling of the value chain.** Vertically integrated utilities are broken into constituent components (e.g. generation, networks and retail). There are two aspects. First, competition is introduced in generation and retail. Competitive wholesale markets[10] (e.g. spot markets, bilateral supply contracts) and operating reserve markets (e.g. ancillary markets) are created to facilitate trading by generators, retailers and customers, and to support system operation, balancing and reliability (Joskow, 2008b). Customers can

---

[9] Example includes the energy crisis of California in 2001

[10] Different models of wholesale market were proposed (see Joskow, P.L., 2008b. Lessons Learned From Electricity Market Liberalization. The Energy Journal. for detailed discussion) but in many of the restructured markets (e.g. Great Britain, Chile, Argentina, New Zealand and Norway), a ‘customer choice’ model was employed. In this model, generators can strike long-term bi-lateral supply contracts with retailers or customers, or sell electricity in a competitive wholesale spot market.

arrange for their own supply with competing retailers[11], while this retail liberalisation has been 'phased in over time or limited to large customers' (Joskow, 2008b; Sioshansi, 2006b; Woo et al., 2003). Second, T&D networks are natural monopolies so should continue to be regulated. Separating natural monopolies from the rest of the value chain is key for retail competition[12] – it ensures equal network access and prevents cross-subsidy (e.g. Jamasb and Pollitt, 2005; Joskow, 2003b). An appropriate framework is needed to ensure quality – e.g. reliability and service standards (Jamasb and Pollitt, 2007; Joskow, 2006b) – and cost-effectiveness[13] of service, and non-discriminatory access (Joskow, 2008b; Joskow and Schmalensee, 1987; Laffont, 1994).

- **Establishment of a system operator.** Short-term system operation entails scheduling of dispatch, physical operation, coordination of generation and other resource types, residual real-time demand-supply balancing and addressing system emergency and contingencies. While pre-restructuring these responsibilities are in vertically integrated utilities, the structural unbundling necessitates appointing a system operator to perform such tasks. System operators are typically responsible for ensuring the system reliability, subject to established requirements based on engineering procedures (Chao et al., 2008), real-time balancing and resource adequacy over long term.

- **Economic signals for the short-run system operation.** Under vertical integration, responsibilities for generation scheduling, dispatch and real-time balancing are centralised within a single utility. In a restructured system, decision-making in these areas is based on market-based pricing or economic incentives of wholesale markets and allocated to constituent parties. For short-term operation, competitive wholesale markets

---

[11] Depending on specific regulatory arrangements, large customers may need to access unbundled T&D services but in most cases, retailers access them on behalf of customers.

[12] In most of the restructured markets in the U.S., distribution and retail are still unbundled, while competitive retailer may offer competitive retail tariffs and access T&D services.

[13] 'Performance-based regulation' or RPI-X framework is established in many markets to impose some sort of price cap or budget constraint, assuming a decline in real cost due to productivity improvement and allowing adjustments for external factors such as price inflation Joskow, P.L., 1997. Restructuring, Competition and Regulatory Reform in the U.S. Electricity Sector. The Journal of Economic Perspectives 11, 119-138..

(e.g. day-ahead or intraday spot markets) allow generation, retailers, traders and customers to trade until 'gate closure'[14], after which system operators will perform their 'residual balancer' role of maintaining real-time balance of the system, by utilising balancing or ancillary services, and operating physical systems within safety limits. As noted in Joskow (2008b), wholesale markets should consist of spot markets that accommodate bilateral contracts and self-generation. For designing wholesale spot markets, in-depth theoretical and practical discussions are found in seminal work such as Hogan (1992) and Hogan (1998). Second, another aspect of this transition to reliance on economic signals is the unbundling of wholesale supply into several system services or '*products'* (e.g. energy, ancillary services, transmission service and even capacity). Such differentiation is intended to reflect distinct aspects of system operation, and recognises attributes of resources (e.g. operational nature, ramp-up time, and constraints) and varying values they can provide. The rationale is to establish efficient price on these system services with different system values[15] (Chao et al., 2008).

- **No party is *directly* responsible for the long-term resource adequacy.** Regulators often mandate regulated utilities to maintain a certain share of generation (e.g. 15-25% of peak demand) as reserve margin to meet reliability standards. Post-restructuring market-based pricing and other economic signals take up the role of directing decisions on investment in generation and technology choice (e.g. Sioshansi, 2006b). A 'functional' competitive market is expected to provide appropriate incentives to ensure adequate – and the right mix of – resources economically efficiently. There is no single constituent party that is directly responsible for the resource adequacy. Generation is rewarded for its energy output and provision of ancillary service, and investment decisions are based on

---

[14] Specific time (e.g. one hour) before relevant settlement period

[15] For example, in ancillary services, spinning and non-spinning reserves are priced in a way recognising that speed of response is a scarce resource for system operation. Separate markets for these system services are designed to allow efficient allocation among multiple parties and settlement in multilateral trade. In the GB system, National Grid – the system operator – procures balancing services with different technical terms (e.g. fast reserve, short-term operating reserve, frequency response) separately through regularly held competitive tendering or bilateral arrangements.

economics (e.g. expected profits and return). In light of this, there tends to be little incentive for generators to maintain 'extra capacity for long-term system reliability' (Finon and Pignon, 2008; Sioshansi, 2008b). However, in practice, the system operators are usually held responsible for the grid reliability so they may put in place measures to promote market incentives for maintaining enough capacity, or at minimum decide how to shed load during scarcity events. In some cases, strategic reserve or other emergency capacity is procured outside of the market to be used during emergency conditions.

- **Market regulatory authorities.** Market reforms do not necessarily mean deregulation, even for generation and retail where competition is introduced. Regardless of the debate on the role and extent of regulation[16], independent regulatory authorities are essential in a restructured market to regulate T&D, guarantee non-discriminatory network access and secure supply, and protect customers (Breyer, 1998; Crew, 1991; Larsen et al., 2006; Newbury, 1999). Other objectives include addressing market externalities and promoting transparency (e.g. Stern, 1997). In the political and regulatory literature, critiques are raised of the status of independent regulatory authorities. First, an independent regulatory authority is vulnerable to regulatory capture caused by low staff turnover due to the technical nature of work and possible close link with regulated parties (e.g. OECD, 1999). Second, it lacks democratic accountability and legitimacy (e.g. Graham, 1998). However, other scholars disagree. It is argued that the expertise of independent regulation limits information asymmetry and facilitates balanced, rational decision-making (Thatcher and Sweet, 2002). It would also mitigate risks by instituting 'good practices' like balanced

---

[16] There are two schools of thinking Sioshansi, F.P., 2006a. Electricity market reform: What has the experience taught us thus far? Utilities Policy 14, 63-75.. On one hand, those in favour of 'light handed regulation' believe in the 'invisible hand' of market so the role of regulation should be kept to minimum to ensure free and fair competition. Examples include generators not required to offer capacity into market or bid in a specific way (e.g. based on short-run marginal cost), and high price caps in wholesale energy market. On the other, some see market failures as justifications for proactive or prescriptive regulation where market players perform in a controlled manner.

and transparent consultations, appropriate incentive regulation, appeal mechanisms and ‘justification of methods and decisions by the regulator’ (Larsen et al., 2006).

Market restructuring and liberalisation can bring benefits. There is evidence that incentives of competitive wholesale markets have improved the operational efficiency and availability of generation (Bushnell and Wolfram, 2005; Fabrizio et al., 2007; Newbery and Pollitt, 1997). In the UK, Argentina, Chile, New Zealand and others, privatisation and performance-based network regulation helped enhance labour productivity and service of distribution networks in terms of losses and outages (Domah and Pollitt, 2001; Jamasb and Pollitt, 2005, 2007; Newbery and Pollitt, 1997). However, there is only mixed evidence on the benefit of *full* market reforms (e.g. complete unbundling, extending retail competition to small customers):

- **There remains disagreement on whether residential and small commercial customers benefit from retail competition** (Morey and Kirsch, 2016; Sioshansi, 2006a, b). Evidence on the propensity of mass-market customers in switching suppliers in different retail markets is mixed (CMA, 2016; Defeuilley, 2009; Joskow, 2008b; Salies and Price, 2004; Sioshansi, 2006b). For some countries, low switching rates led scholars to question the value of retail competition to small customers (Sioshansi, 2006b). Barriers may exist for smaller customers to shop around and compare options (e.g. access to information, metering arrangements) or for retailers to attract customers (e.g. limited unbundling of distribution and retail)[17] (Defeuilley, 2009; Olsen et al., 2006). However, a competitive retail market has the potential of encouraging innovation in products and customer choice including dynamic pricing programmes (Littlechild, 2006; Morey and Kirsch, 2016).

---

[17] In many markets with retail competition (e.g. the US, Spain and France), regulated default service price is provided to smaller end-users by distribution companies or retailers, because of their less propensity to switch suppliers. Since default service price is typically set below wholesale energy cost, that makes it difficult for competitive retailers to attract customers, especially given the higher cost of serving smaller customers Defeuilley, C., 2009. Retail competition in electricity markets. Energy Policy 37, 377-386, Joskow, P.L., 2008b. Lessons Learned From Electricity Market Liberalization. The Energy Journal..

- **There is no prevailing evidence that restructuring and retail competition lead to lower retail prices *necessarily*.** Steiner (2001) and Hattori and Tsutsui (2004) found some evidence of price reduction in OECD countries in the period to 1999 but qualified that it was difficult to attribute it to reform initiatives. In the U.S., exogenous factors like rising fuel cost pushed up retail price and the market restructuring failed to close the gap of high-cost and low-cost states (Pfeifenberger et al., 2007; Sioshansi, 2008b). This, and the California electricity crisis of 2000-01 and reliability incidents in New York and parts of Europe in 2003, led to a backlash against the market restructuring, with some states delaying the process or rolling back earlier reform efforts (Jamasb and Pollitt, 2005). The consequence is a 'hybrid' structure with a mix of regulated vertically integrated utilities and competitive entities, on an 'uneven playing field' (Sioshansi, 2008b).

- **The merits of integration, particularly of generation and retail are disputed** (Pollitt, 2008; Sioshansi, 2008b). Utilities in some European countries argue that a strong market position can strengthen their power in negotiating gas contracts, and many unbundled utilities in the UK re-bundled the generation and retail businesses. It is shown that some degree of integration can be more efficient and help manage risks and price volatility (Chao et al., 2008; Joskow, 2005). Thus, some scholars argue that there is a balance or 'middle path' between vertical integration and full restructuring. Chao et al. (2008) suggested that allocation and management of market risks would be one key determinant of an optimal balance. However, there is a trade-off with market competition, if such integration creates barriers to new entrants (Bushnell et al., 2008; Mansur, 2007).

This thesis focuses on the debate on how the restructured market should be designed to ensure the long-term capacity adequacy. Given the key role of electricity in socioeconomic activities, it is necessary to ensure a secure supply, by having adequate capacity to meet peak demand as well as reserve margin. 'Functional' wholesale markets, in theory as discussed above, are expected to give appropriate economic signals to ensure adequate, and the right mix of, resources in the right location. In their early years during the 1990s, reformed markets attracted a large scale of new investment in generation capacity (Joskow, 2005). However, in many countries, creating incentives for generation investment is gradually seen as an emerging issue, due to a series of factors like tight financial conditions, market imperfections that depress the wholesale energy price and regulatory or market design uncertainty (Cramton and Stoft, 2006; Joskow, 2006a; Joskow, 2007, 2008a). Moreover, more stringent environmental regulation and changes in market conditions (e.g. higher share of intermittent renewables and lower wholesale price) also put pressure on fossil fuel thermal capacity in some countries. Considering this, many jurisdictions have established or are planning to set up a capacity market to *explicitly* remunerate capacity resources for being available, thus ensuring the system reliability and incentivising new investment. The capacity market is typically a centralised mechanism that relies on competitive auctions to procure resources and establish their capacity value. As explained in Section 2.4.4, the capacity market is a competitive, market-wide approach, different from regulatory resource planning, administratively set capacity payments or bilateral markets where retailers mostly self-supply or contract with suppliers on a long-term basis (Spees et al., 2013). In some of the forward capacity markets, demand-side resources like EE and DSR already contribute to the capacity adequacy in direct competition with supply resources (e.g. generation, imports from neighbouring systems).

The capacity market is *one* solution to the long-term resource adequacy or ‘missing money’ issue. Reforms in the wholesale energy markets can address the root cause of long-term resource concerns, while the practicality and extent of reforms may justify the capacity market as a viable option. The following sections review the literature of ‘missing money’ issue, the debate on whether the capacity market would be the best solution, especially in the context of high penetration of intermittent renewables, and the types of capacity markets and their key design characteristics.

2.4.3. The 'missing money' issue for capacity adequacy in restructured markets

For long-term capacity adequacy, restructured markets depart from the regulatory planning based on 'cost-of-service' and reliability standards, to a new paradigm where decisions are made by individual investors based on economic signals. In an ideal model, the market-clearing price would provide appropriate signals to direct decisions related to investment, production and distribution (Joskow, 2008b; Roques, 2008). Theoretically speaking, in a wholesale energy market, *'scarcity rent'*[18] in shortage events (if demand can set the clearing price in those events) and *'inframarginal profits'*[19] can provide the margin needed above the short-run marginal cost to enable the existing generation to undertake refurbishment and earn a return, and attract new investment (Adib et al., 2008). In the long-term equilibrium, scarcity rent and inframarginal profits should cover the 'amortised fixed cost' of generation resources (Adib et al., 2008; Oren, 2005).

However, in the actual market place, two factors may lead to market signals being too weak to incentivise new capacity investment and maintenance of adequate resources – the so-called 'missing money' issue (Spees et al., 2013). First, scarcity rent is often suppressed. This is because most wholesale markets have price caps or other market mitigation measures (e.g. out-of-market capacity procurement) to address potential price spikes. The rationale is to mitigate the market power risk and the political risk of high and volatile wholesale prices, due to two characteristics of electricity (Hogan, 2017). On one hand, as electricity is yet to be economically stored on a large scale, it is 'susceptible' to market manipulation if any dominant actors withhold production. On the other, the electricity demand tends to be relatively unresponsive to price or 'inelastic', due to the typical retail tariff that does not reflect the marginal cost of generation at different times. Second, the reserve capacity needed to meet administrative reliability standards (e.g. one loss of

---

[18] 'Scarcity rent' refers to the difference between marginal demand offer accepted (i.e. the value to demand where generation can just meet demand, in shortage events) and marginal cost of peaking unit (i.e. marginal cost of the most expensive kWh served by generation).

[19] 'Inframarginal profits' are the difference between market clearing price and marginal cost of respective generation.

load event in 10 years) is often higher than the economically efficient level (Bowring, 2008, 2013b; Spees et al., 2013). This has the effect of suppressing price levels in wholesale markets generally.

Moreover, with respect to retail, competitive market conditions and risk management mean that there is little incentive for market players to secure long-term contracts and maintain reserve requirements. As noted in Adib et al. (2008), one unintended consequence of a competitive retail market where retailers are not required to ensure the sufficiency of resources in a multi-year frame is free-riding on the public good of system reliability. Competitive retailers, especially in the early stage of retail competition, may lean towards relying on wholesale spot markets – in some markets, uncertainty about market share (e.g. due to customers switching) and generation overcapacity mean a cost-structure disadvantage in taking up long-term generation contracts. Other reasons like low offer caps in the wholesale market, fluctuation in fuel price and uncertainty about market design may contribute to the reliance on wholesale spot markets.

2.4.4. Approaches to promoting capacity adequacy

There are three solutions to address the ‘missing money’ issue (Bowring, 2013b), reflecting differing schools of thinking on priorities, market structure, balance of theory and practicality, and to some extent, how feasible it is to implement relevant remedies and in what order. Different pathways are undertaken for ensuring capacity adequacy across jurisdictions.

First, regulatory approaches include *direct capacity payments* and *bilateral contracts* subject to regulatory review. Direct capacity payment, set administratively based on the amortised fixed cost of marginal technology as the supplement to marginal energy cost (Adib et al., 2008), is made to new generation. Countries using this approach include Argentina, Chile, Peru, Colombia and Spain (Bowring, 2008). For the Southwest Power Pool, Midcontinent Independent System Operator (MISO) and California, retailers or Load Serving Entities (LSEs) are required to procure sufficient capacity to cover customers’ peak demand plus reserve margin (Spees et al., 2013).

Since these systems are primarily vertically integrated, most of resources are secured via self-supply or long-term bilateral contracts, usually as part of the cost-of-service regulation, although MISO operates a capacity market for incremental capacity needs.

Second, one market-based approach is to *establish a capacity market as a complement to energy market*. This constitutes a ‘top-down or accounting-based approach’ in that shortfall of generation, net of revenue from energy and ancillary markets, is offset with a payment for ‘capacity’ or being available (Adib et al., 2008). As opposed to reforming the energy market, it introduces a ‘capacity product’. A separate market needs to be created to procure resources based on capacity needs set in line with reliability requirements. The cost of capacity markets is allocated to retailers and passed through to customers. Different from bilateral contracts, a capacity market is a competitive mechanism, which can be administered *centrally* (i.e. the system operator or other single-buyer procures on behalf of retailers based on a centralised estimate of capacity needs, e.g. PJM, ISO-NE, GB) or *de-centrally* (i.e. capacity owners trade capacity certificates with retailers in public auctions or bilaterally, e.g. France). Capacity markets of different types are created in the U.S. (e.g. PJM, ISO-NE, NYISO), while some countries in Europe (e.g. the UK, France, Italy, Ireland and Poland) have established the capacity markets or are considering doing so.

Third, *energy market can be reformed* to address the root of ‘missing money’ issue. This approach accepts that the crux of issue is risk management in a competitive market, and that by allowing the wholesale energy price to reflect scarcity rent and encouraging long-term bilateral contracts, a ‘risk-sharing’ is created between generation and customers to promote capacity adequacy (Adib et al., 2008). Price caps and other mitigation measures are restricted – voluntary risk management, complemented with mandatory hedging requirements, can be used to protect customers. Variants of ‘energy-only resource adequacy mechanism’ are implemented in Australia and ERCOT, where there is evidence that high price caps result in ‘increased voluntary bilateral contracting’ like option or multi-year contracts with peaking plants to hedge against price hikes

(Adib et al., 2008). Other initiatives are promotion of DSR in energy market, refined definition of operating reserve products, and cost-effectiveness review and adjustment of reliability rules (Joskow, 2007, 2008a; Roques, 2008).

While all these approaches can ameliorate the ‘missing money’ issue, there are pros and cons for each one of them. Administrative direct capacity payment is not a competitive process so may not efficiently reveal the value of capacity or can lead to economically inefficient procurement of capacity (EC, 2016a; Pfeifenberger et al., 2009). Bilateral contracts, while readily usable for new capacity, have some drawbacks like the lack of transparency and competition, and the difficulty in separating capacity from energy in the bundled contracts (Bowring, 2013b; Spees et al., 2013). A capacity market has several advantages, like increased transparency, lower transaction costs and effective competition between resources. This makes a capacity market preferable as a backstop mechanism for markets with retail competition (Pfeifenberger et al., 2009). For example, for California that uses bilateral procurement, reforms of existing practices or a forward capacity market are recommended to improve the efficiency in ensuring resource adequacy (Pfeifenberger et al., 2012).

However, there is less of a theoretical consensus on whether a capacity market should be created to address the capacity adequacy issue, as opposed to reforming the wholesale energy market and keeping the ‘energy-only’ market structure. In a way, this reflects differential judgment on the feasibility and risks of implementing associated measures, and whether reliability can or should be entirely left to market forces – as characterised in Adib et al. (2008), it is a matter of choice.

On one hand, the appeal of the ‘energy-only’ market is its theoretical elegance and minimal regulatory intervention in that market incentives, manifested in voluntary interactions, determine an efficient level of reliability and investment needs (e.g. Hogan, 2005; Pfeifenberger et al., 2009). A capacity market, with its administrative procurement target, resembles a regulatory planning regime under vertical integration (Hogan, 2005). It is regarded as a patch to an incomplete market restructuring, which is without adequate competition, responsive demand and risk management (Schubert et al., 2006). For ERCOT in the U.S., its ‘energy-only’ market does not attract adequate new investment in recent years and developers attribute the low market price to frequent ‘out-of-market’ reliability measures (Adib et al., 2013). However, a decision is made to improve scarcity pricing with higher price caps, without setting up a capacity market.

On the other, it is argued that the absence of responsive demand-side, due to technological and market reasons (e.g. metering and tariffs), makes it necessary to create a capacity market (e.g. Bowring, 2013b; Cramton et al., 2013; Cramton and Stoft, 2005). This is because during scarcity events, with an inelastic demand, the wholesale price would rise almost without a limit, if a price cap was not in place. While the price cap can be set at a level reflecting the value customers place on reliability (i.e. value of lost load, or VoLL), it is difficult to estimate the VoLL and a high price cap may increase the risk of market power abuse (Cramton et al., 2013). As discussed by Bowring (2008), compared with a capacity market, it would be as complicated, if not more, to manage the scarcity pricing in a way that leads to appropriate net revenues and desired reliability, while also preventing market power abuse. Moreover, in Australia, the oft-cited example of an ‘energy-only’ market, government ownership and public-private partnership for generation seem to be a critical factor underlying its capacity adequacy (Pfeifenberger et al., 2009). Some empirical assessment (e.g. for PJM) shows that a well-designed capacity market can incentivise new investment and ensure reliability in an integrated way with energy and ancillary markets (Bowring, 2013b).

Notwithstanding this theoretical divide, in practical terms, there is a gradual convergence of opinions. While there should be a focus on reforming the energy markets, some practical or political factors may make it necessary to have a capacity market. As noted in Hogan (2006), improved scarcity pricing may not solve all the issues (e.g. lumpy generation investment in load pockets), and complementing the wholesale market reforms with a capacity market would grant credibility to the reforms themselves. Some scholars (e.g. Joskow, 2008a; Roques, 2008) argue that reforms to the wholesale energy market may not be fully implemented and it takes time. Moreover, relying on an ‘energy-only’ structure requires a high level of market monitoring to distinguish scarcity pricing from market power abuse. These concerns have led some to see a capacity market as a supplement to the wholesale market reforms, which nonetheless gradually lessens the reliance on the former (Hogan, 2006; Joskow, 2008a; Roques, 2008). After all, the political risk of a public backlash against a reliability failure means that regulators may not ‘trust markets to determine the optimal level of reliability in the near future’ (Roques, 2008). Furthermore, market uncertainties (e.g. future market design, including definition and revenue expectations of balancing services in a system with a high share of renewables) would make forward, long-term contracts through a capacity market desirable (Newbery, 2016).

However, the capacity market has limitations, particularly in the context of low-carbon energy transition, which reaffirms the need to prioritise the energy market reforms. For a system with a high penetration of renewables, there is an emerging view that a capacity market as currently designed may not ensure procurement of the *right mix* of resources (Gottstein and Skillings, 2012; Hogan, 2017). A large-scale integration of renewables increases the need of flexible resources that can ramp up or down rapidly to help balance the system (IEA, 2014b). As discussed in Hogan (2017), *flexibility* is distinct from *capacity* in that the latter refers to ‘a unit of firm or reliable capacity’, and the energy price reflecting short-run marginal costs in energy market and the marginal cost of system balancing is the ‘most reliable’ way to value flexibility. In this light, the capacity market is not the optimal option, because of its focus on the capacity value not the flexibility of resources and the effect of ‘diluting’ energy prices, which are best placed to reflect the value of flexibility. Therefore, the priority should be to correct distortions in the energy market price (e.g. price caps, failure to reflect marginal cost of balancing services in the clearing price of energy market, exclusion of demand-side as a resource to support reliability). In recognising the challenges and efforts in doing so, provisional administrative shortage pricing may be introduced to allow prices to reflect the full marginal cost of energy and balancing services.

However, Hogan (2017) does not dismiss the capacity market – if a decision is taken to create a capacity market, policymakers should recognise and reward the differing flexibility value of resources to the extent possible, while still focusing on correcting the price distortions.

A recent sectoral inquiry of the European Union echoes the view that a capacity market should be a supplement rather than a substitute to energy market reforms. In Europe, the concern about supply adequacy has led countries to create or contemplate capacity mechanisms (Fig. 2-3). The sector inquiry finds that the electricity market is limited in producing adequate incentives for the investment in reliable and flexible resources, by scarcity pricing in shortage events (EC, 2016b). Several factors have contributed to this, including (EC, 2016b):

- **Wholesale energy price caps** imposed explicitly or implicitly by balancing market rules;
- **Lack of locational pricing for investment** due to delineation of bidding zones not considering transmission constraints and reliance on *'out-of-market re-dispatching'*; and
- **Uncertainty of future market developments.**

The inquiry concludes that removing these limiting factors should be the priority. It sees long-term hedging contracts between generators and retailers as a solution to manage spot price risks, citing examples in Australia and Germany. Promoting DSR and setting appropriate bidding zones are also necessary. Recognising the practical challenges of these market reforms (e.g. time needed, extent of reform), the inquiry sees the capacity market as a complementary solution, justified only if economic reliability standards[20] are unlikely to be met by market itself[21]. If the concern about resource adequacy is short-term, EC (2016b) notes that strategic reserve is preferable, given its limited meddling with the energy market.

---

[20] Based on value of lost load (VoLL)

[21] Includes identifying market failures, and quantifying the impact on investment and reliability, and the gap with economic reliability standards

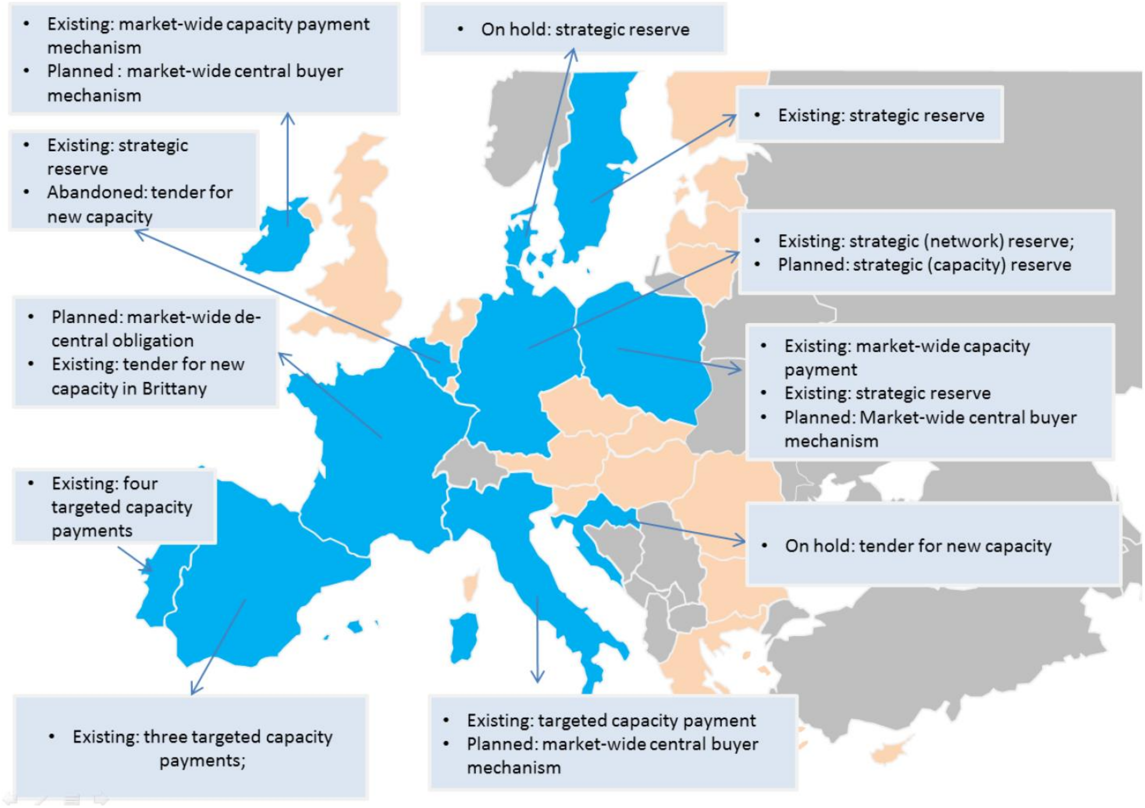


Fig. 2-3. Type of capacity mechanisms in 11 countries in European Union

Source: EC (2016a)

2.4.5. Key designs and types of capacity markets

In a nutshell, a capacity market is an organised, competitive mechanism where resources to meet reliability requirements are procured and rewarded. For each delivery period (e.g. from one month to one year), qualified capacity enters auctions and if cleared, will commit to deliver (e.g. generate or reduce demand) based on the definition of capacity obligations in return for capacity payment. Besides capacity auctions for the whole system, locational capacity requirements and auctions may be done for regions with T&D constraint (Pfeifenberger et al., 2009). As discussed later, the designs of capacity markets vary across jurisdictions, reflecting regulatory conditions and policy considerations of the pros and cons of design options. However, a few principal characteristics are common:

- **Capacity auctions are open to a variety of resources that compete based on the cost of capacity.** Existing and new resources are eligible to offer, and once the eligibility requirements are met, different technologies and measures of capacity contribution (e.g. generation, storage or reducing electricity load) can compete in auctions. In other words, capacity is traded as a commodity in technology-neutral auctions, unless procurement ceilings are put in place for certain resources. To reflect the difference in how resources deliver their capacity value, different capacity products, which define the parameters for delivering their capacity, are designed (e.g. peak savings for electricity use reduction and associated M&V requirements). However, as discussed in Section 2.5, not all capacity markets have allowed electricity use reduction to make capacity offers. For DSR, while many capacity markets do allow it to participate, it may face different treatment from other resources in areas of contract length, eligibility requirements and interaction with energy market.

- **Capacity resources need to deliver as required or otherwise face a financial penalty for any shortfall in the capacity commitment.** In other words, the financial incentives in the capacity market are based on performance. For electricity use reduction, it means a minimum amount of peak demand reduction, as defined by the market rules. In some markets, there is an incentive for over-delivery of capacity (e.g. redesigned ISO-NE).

Different types of capacity markets are set up. Some key aspects of design where the capacity markets differ are summarised below:

- **Forward period.** Capacity procurement can occur with a short lead time (e.g. months before delivery time, e.g. MISO and NYISO) or on a forward basis (e.g. years between the main auction and delivery, e.g. PJM, ISO-NE, GB and France). One disadvantage of a short lead time is potentially little time to respond to capacity deficiencies by investing in new resources, which can lead to steep capacity supply curve and result in higher price volatility or market power abuse (Pfeifenberger et al., 2009). In comparison, a forward capacity procurement allows new capacity to take part and increases market competition.

- **Centralised vs. de-centralised.** In many major systems, a centralised capacity market is created as a mandatory mechanism for acquiring adequate resources or just residual capacity[22] (Spees et al., 2013). For these markets, a single buyer (e.g. system operator) would determine the capacity needs and procure resources on behalf of retailers, the cost of which is then allocated to them and eventually customers. In regions without full retail competition (e.g. PJM, ISO-NE and NYISO), incumbent utilities are subject to resource adequacy requirements and have the flexibility to secure bilateral contracts. Meanwhile, in France, a voluntary, de-centralised capacity market is created for trading capacity certificates between retailers and capacity operators, without a centralised process for determining the capacity needs (EC, 2016a).

- **Demand curve.** To clear capacity auctions, a demand curve is essential. While in a de-centralised auction (e.g. France) the demand curve is an aggregate of estimated demand by individual retailers, the centralised markets (e.g. PJM, NYISO, MISO and GB) use an administrative demand curve determined based on the system-wide capacity needs. Two main ways exist for constructing a demand curve: 1) a vertical curve with a fixed capacity requirement; and 2) a downward-sloping curve varying resource requirement with the capacity price (Spees et al., 2013). While simple to institute, a vertical demand curve has some disadvantages, including price volatility, market power risk and inability to reflect incremental reliability value after the procurement target is met (Pfeifenberger et al., 2009). However, it depends on how the procurement process is done. The Forward Capacity Market of ISO-NE is a zonal three-year forward procurement mechanism, using descending clock auctions (i.e. price drops in each round and resources may exit

---

[22] For MISO, this is due to the existence of vertically-integrated utilities and cost-of-service regulation.

> at a given price, until procurement target is met). This multi-round auction improves the 'efficiencies and pricing transparency' (Pfeifenberger et al., 2009). At the same time, a downward-sloping curve, i.e. variable resource requirement (VRR) demand curve, can address these concerns. VRR allows the quantity of acquisition to vary with the capacity price – i.e. more resources beyond the capacity target can be procured as the price drops. While it may not reflect the actual incremental value of increased reliability[23], it reduces price volatility (Pfeifenberger et al., 2009). VRR was first adopted by NYISO (Adib et al., 2008) and capacity markets of PJM, GB and France adopt the VRR approach.

This thesis sets out to examine what the central designs of a capacity market, reflected in the EDR Pilot in the UK (Section 1.1), would mean for promoting electricity use reduction. It focuses on *forward capacity markets*. It is primarily because the EDR Pilot and the GB Capacity Market follow the design of a forward capacity market, and the rich experience of some forward capacity markets (e.g. PJM, ISO-NE) in integrating electricity use reduction. In extrapolating the findings, it considers whether (and if so, to what extent) the forward period would be a relevant factor underpinning the role of the capacity market in promoting electricity use reduction. The following section summarises the status of demand-side participation in the restructured markets, particularly the capacity markets.

2.5. Participation of demand-side resources in the restructured markets

Vertically integrated utilities may introduce DSM programmes to reduce system peak demand and promote system reliability and economic efficiency. However, the procedure is regulatory and the focus is on resource adequacy. It is not a priority or a difficulty to provide dynamic

---

[23] VRR demand curve does not necessarily reflect the demand bids that would be put forward by capacity buyers – there is one point on the curve reflecting the capacity target at the estimated net costs of new entry (i.e. 'Net CONE') of peaking resources (i.e. Net revenues needed, after deducting proceeds from wholesale energy market and ancillary services, to cover fixed costs), with curve slope determined administratively.

economic signals and explore the potential of flexible demand-side for other aspects of system operation such as balancing (Adib et al., 2008).

Market restructuring and liberalisation marks a new paradigm of demand-side participation from three dimensions. It reflects the departure from a regulatory approach of deploying demand-side resources by a single utility, to one relying on decentralised decisions based on market dynamics:

- **Liberalised market access.** In many systems, an opportunity has emerged for new entrants (e.g. curtailment service providers), and incumbent utilities, to develop demand-side resources for direct offering in wholesale energy markets or ancillary markets, thus broadening the type of providers for demand-side resources and the range of system services they can provide (Cappers et al., 2010; Hurley et al., 2013).

- **Differentiated system services.** Unbundling of electricity supply into an energy market, ancillary services and even capacity market in some jurisdictions allows 'products' from demand-side resources to be differentiated and remunerated for specific system services. Depending on the market, demand-side resources may compete against other resources to set a market price for a given system service or be procured in dedicated programmes. Apart from being integrated in the wholesale market, demand-side resources may also be maintained by utilities as their risk-hedging positions.

- **Distributed benefits.** The benefits of demand-side resources are distributed along the unbundled supply value-chain, underscoring a need for coordination for utilising these resources and sharing associated costs like smart metering (Zarnikau, 2008).

2.5.1. Rationales for utilising demand-side resources in the restructured markets

Integrating demand-side resources in wholesale markets has multiple benefits. First, cost-effective demand-side resources can reduce the system costs and promote economic efficiency by avoiding construction of peaking generation, lowering the wholesale energy price or providing cost-efficient system balancing (e.g. Faruqui and George, 2002; Jenkins et al., 2011; Neme and Cowart, 2014; Rosenzweig et al., 2003; The Brattle Group, 2007) . For example, in the forward capacity market of PJM, the cleared EE and DSR in the Base Residential Auction for 2018/19 reduced the clearing price in unconstrained zones from $231/MW-day to $165/MW-day (Monitoring Analytics, 2016).

Second, particularly for DSR, its integration in the wholesale energy market contributes to a fully competitive market (Zarnikau, 2008). Demand responsive to real-time prices strengthens the elasticity of demand and increases competition during scarcity events, thus reducing the volatility of price (Centolella, 2010). It is argued that price-elastic demand, by competing against generation, would lower the need of price mitigation measures instituted to counter market power abuse and ‘allow scarcity pricing’ (Adib et al., 2008; Zarnikau, 2008). For long-term resource adequacy, in an ideal model, adequate elastic demand would be able to respond to marginal pricing signals and provide individualised value for reliability.

Third, participation in the wholesale markets is regarded as a lever to support the development of demand-side resources. As discussed in Chapter 7, proceeds from the wholesale markets can reduce the need of securing funding from other means, particularly public budget and energy bill levies to support regulatory EE obligations (e.g. MEGEEPA, 2015). For DSR, participating in wholesale markets and responding to market signals is perhaps the only way to realise its system values in a restructured market. In the UK, one objective of integrating DSR in the GB Capacity is to support the DSR market, with the long-term interest in developing price-responsive DSR in the wholesale energy market.

2.5.2. Mechanisms for participating in restructured markets

a) Energy efficiency (EE) and electricity use reduction

Restructured electricity markets are designed without much focus on electricity use reduction. Consequently, it is largely left to the realm of public policies like utility EE obligations or 'market transformation programme' (e.g. product standards, incentive for developing market demand). In many places, while the competitive market takes over the role of directing the planning and operation of generation, the regulatory framework for promoting EE (e.g. saving targets, budget, and eligibility) is largely maintained. It *does not* necessarily mean that the *delivery* of EE programmes or policies is not employing market forces. Many EE obligation schemes across the world (e.g. the UK, US, France, Italy and China) are designed to let the market decide how much savings to achieve and/or at what price, what technologies and/or customers to target, and what business models to pursue (IEA, 2017). Such scheme designs are utilising a competitive market. What is distinctive herein is that such competition is within the constraints of regulatory objectives (e.g. savings targets, segments of opportunities to target) and *does not occur directly against* other resources. If the utility EE obligation is seen as a kind of resource acquisition, it takes place outside the wholesale markets that are set up for the same purpose (SPEER, 2013). Peak savings of electric EE are reflected in the demand curve for the wholesale energy market. However, as it is not part of the 'merit order', electricity use reduction is not remunerated in the wholesale electricity markets.

Integration of electricity use reduction remains an understudied area, due to the limited efforts to do so in actual market implementation. Electricity use reduction is non-dispatchable – once EE measures are installed, their peak impacts are unable to change in response to the wholesale prices. Thus, electricity use reduction may not take part in a full range of wholesale markets. However, electricity use reduction can contribute to at least two markets.

- **Forward capacity market.** Electricity use reduction may qualify as a capacity resource in the capacity market. The forward capacity markets in ISO-NE and PJM already allow EE to compete against other resources, offering a route for EE to take part in wholesale markets (Gottstein and Schwartz, 2010). The GB Capacity Market is also exploring this in the EDR Pilot (DECC, 2014d).

- **Local network reliability.** Under the network regulation, electric EE can be procured to address local reliability issue and defer or avoid T&D reinforcement (Anthony and Foley, 2014; Neme and Sedano, 2012).

In principle, electricity use reduction can be remunerated from the wholesale energy market, although no market has taken this approach (SPEER, 2013). In theory, for a settlement period, the incremental value of electricity use reduction is the difference between the actual clearing price and the counterfactual clearing price that would otherwise have been without it. However, it does require a robust estimate of ‘profiles’ of load impacts of various EE measures to be applied in a diversity of conditions (e.g. end-uses, usage patterns, weather) – an almost insurmountable task. Thus, in an ‘energy-only’ market without a capacity market that *explicitly* rewards capacity value, the prospect for EE to take an active part in the wholesale competition is limited.

b) Demand-side response (DSR)

DSR can be divided into two types, i.e. *dispatchable* and *non-dispatchable*, depending on how firm the response is to pricing signals or other economic incentives (Fig. 2-3). For a system operator, dispatchable DSR is controllable and non-dispatchable DSR is less predictable since it depends on the voluntary response of customers to pricing (Hurley et al., 2013). For triggering the load response, dispatchable DSR can respond to real-time pricing signals (e.g. bidding into the wholesale energy market) or system reliability conditions – this can be further divided into short-term ancillary services (e.g. reserves and frequency response) or resources for long-term resource adequacy that are called during scarcity events. Detailed description of each DSR product can be found in Liu et al. (2015), FERC (2009) and Brown (2015).

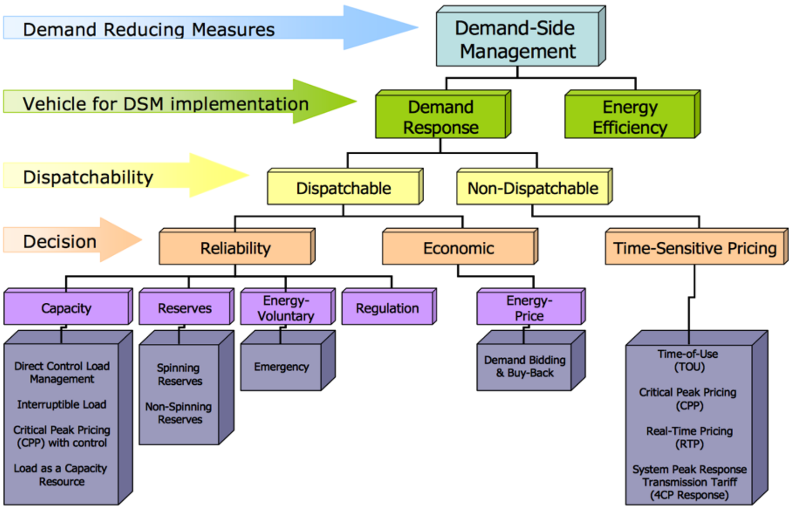


Fig. 2-4. Classification of demand-side response (DSR) resources

Source: NERC (2013)

In the restructured markets, dispatchable DSR can integrate with various wholesale markets to clear the market price of system services, or be procured separately and dispatched in response to market signals or used as a hedging position of retailers in the event of high wholesale energy price (Hurley et al., 2013). Compared with EE, DSR can provide a wider range of system services. For a detailed description of routes for DSR in the restructured markets, particularly for economic response and ancillary services, please see Hurley et al. (2013), Liu et al. (2015), Cappers et al. (2010), Cappers et al. (2013) and Faruqui et al. (2010).

- **Resource adequacy.** For systems with the capacity market (i.e. PJM, ISO-NE, MISO, NYISO, GB), DSR can offer as capacity resource and compete with generation and other resources. If a capacity market is not in place, dedicated DSR schemes triggered by pre-set reliability conditions may be used to procure resources for use during scarcity events and system contingencies. For example, in the UK, the Demand Side Balancing Reserve

(DSBR) was introduced to procure load reduction or embedded generation from large users during winter peak, as the 'last-resort' – it is a temporary measure before the first delivery year of the GB Capacity Market.

- **Economic response.** In some restructured systems, particularly in the US (e.g. PJM, ISO-NE and NYISO), DSR can directly bid into wholesale energy markets (e.g. day-ahead or real-time markets) during high price periods or be dispatched during that time in response to the wholesale price without affecting it. Different from non-dispatchable DSR that also responds to a pricing signal, economic response in the wholesale energy market, if cleared, is committed to deliver. For example, in NYISO, DSR can offer into the day-ahead energy market in a similar way to generation, subject to a minimum bid price to ensure it only participates during high price periods. In ISO-NE, DSR can either participate in the Price Response Programme where customers can voluntarily lower load when the day-ahead wholesale price exceeds $100/MWh[24], or Day-Ahead Load Response Programme where DSR can bid up to the cleared day-ahead market price.

- **Ancillary services.** Many markets in the US and Europe procure DSR as a resource for the operating reserve (e.g. spinning and non-spinning reserve as 'back-up' to respond to sudden loss of power or demand surge) and short-term balancing (e.g. frequency response and regulation service for maintaining real-time system balancing). For example, in the UK, the Short-Term Operating Reserve (STOR) requires resources including DSR to respond within 4 hours[25] of dispatch from the system operator and maintain response (e.g. load reduction for DSR) for at least two hours.

While the use of DSR depends on a multitude of factors such as regulatory provisions, market structure and system needs, it is most common to use DSR for supporting system reliability. In

---

[24] In this case, DSR does not clear in the real-time energy market. It is an 'out-of-market' programme to subtract from the load to be procured in real-time energy market, and its cost is allocated to load outside the real-time market.

[25] Typically, resources that can respond within 20 minutes are procured

the US, the Federal Energy Regulatory Commission conducted surveys on the type and scale of DSR maintained by retailers and/or offered directly by third-parties in wholesale markets (Fig. 2-4). In 2012, dispatchable DSR for resource adequacy such as curtailable programmes and direct load control (DLC) constituted nearly 70% of total reported potential peak demand reduction, although there is some DSR contributing to economic response and ancillary services. For regions covered by ISOs/RTOs in the US, dispatchable DSR for resource adequacy (e.g. emergency curtailable programmes, participation in the capacity market) accounted for a major share of total potential peak reduction of DSR in the wholesale markets (Fig. 2-5). In Europe (e.g. Sweden, Finland, the UK, Italy and Spain), utilities have many years of experience in using various forms of dispatchable DSR (e.g. DLC, interruptible programmes), typically from large industrial users, to support resource adequacy, while there is successful implementation of non-dispatchable DSR tariffs like TOUs (Torriti et al., 2010).

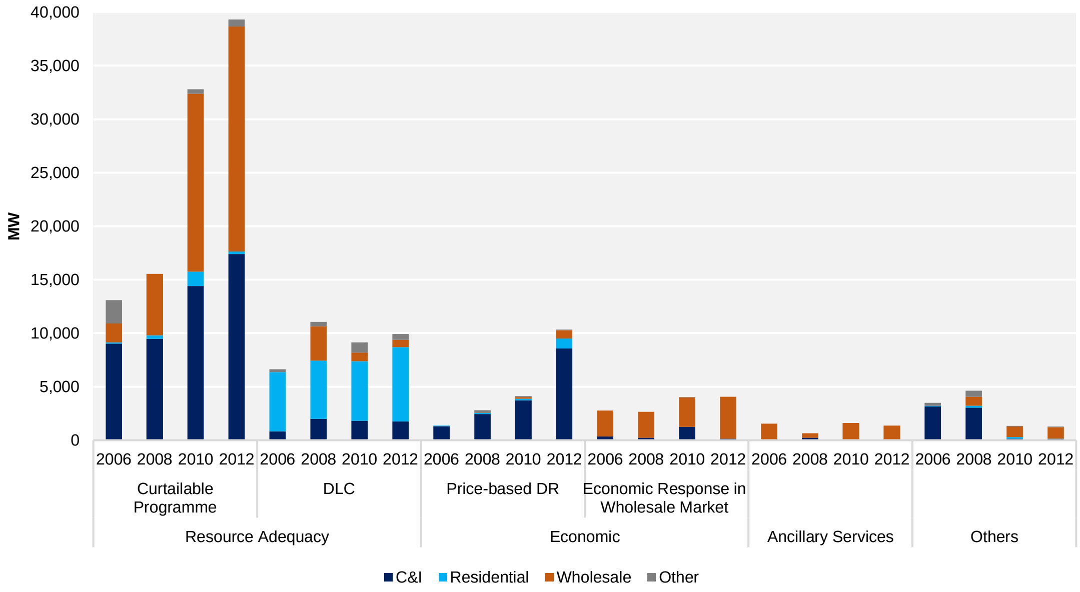


Fig. 2-5. DSR programmes and their reported potential peak demand reduction in the FERC surveys

Source: FERC (2006, 2008, 2011, 2012)

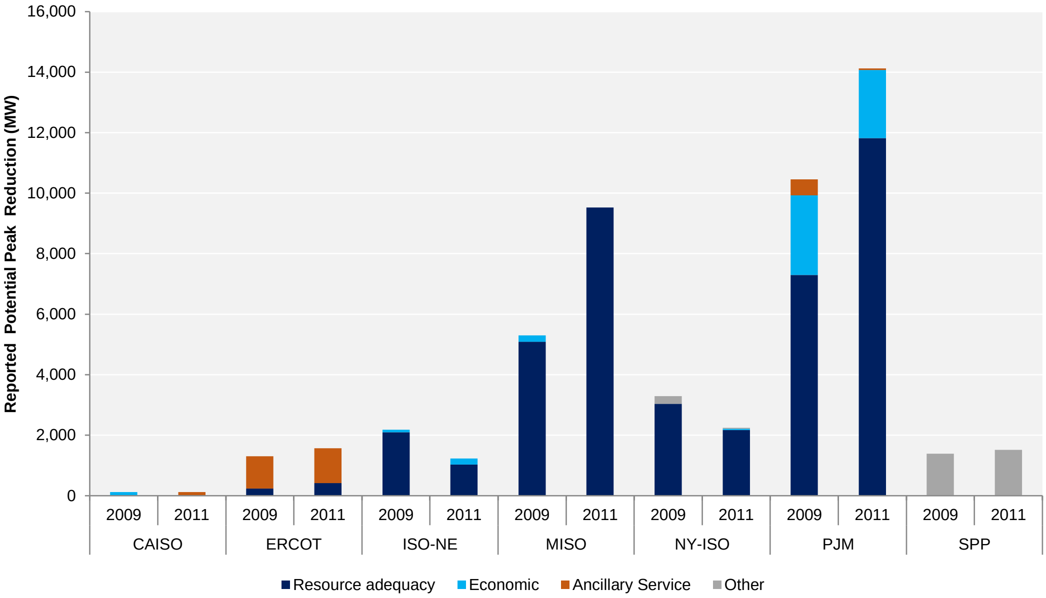


Fig. 2-6. DSR programmes in RTOs/ISOs wholesale markets of the US and potential peak demand reduction

Note: CAISO – California ISO; ERCOT – Electricity Reliability Council of Texas; ISO-NE – ISO New England; MISO – Midwest ISO; NYISO – New York ISO; PJM – PJM Interconnection; and SPP – Southwest Power Pool

Source: Adapted from FERC (2011, 2012)

Deployment of DSR may face barriers like technological infrastructure (e.g. smart metering), customer engagement, uncertainty of value and absence of an enabling regulatory framework for DSR and third-party participation (e.g. Darby and McKenna, 2012; Greening, 2010; Nolan and O'Malley, 2015; Shen et al., 2014; Strbac, 2008). For integrating DSR in the wholesale markets, there are at least three important issues. First, regulatory provisions should be in place to make the wholesale markets accessible to DSR. In Europe, the Energy Efficiency Directive, network codes and state aid guidelines provide legal backing to promote DSR alongside supply-side and other demand-side measures in a non-discriminatory way in capacity, ancillary and balancing mechanisms (SEDC, 2015). As noted in Cappers et al. (2010), while the design of market initially focused on supply-side in the U.S., the FERC and some state regulators made efforts to ensure that market rules provide opportunities for DSR. Examples are Order No.890 (i.e. allow DSR to provide ancillary services and contribute to transmission network planning in a comparable way to traditional measures) and Order No.719 (i.e. require wholesale markets to allow bids from aggregators). Second, appropriate products of DSR need to be defined to reflect resources' technical capability and system needs. This defines the parameters of load response (e.g. trigger, frequency and length of response) and compensation arrangements – it determines the type of system services a given DSR can provide (Centolella, 2010; Walawalkar et al., 2010; Zarnikau, 2010). Third, how DSR is treated in the wholesale market (e.g. financial compensation, eligibility) can have important implications for the economics of DSR and its scale of participation. In the U.S., the FERC Order No.755 requires DSR to be paid, for regulation services, based on the ramping and accuracy of response (Hurley et al., 2013). As discussed in Chapter 7, subjecting DSR to performance requirements for supply resources can increase barriers. One of the most high-profile debate is on the FERC Order No.745 that requires DSR in the wholesale energy market to be paid the full energy market price (i.e. locational marginal price or LMP), if the resource is cost-effective[26]. Opponents argue that rather than LMP, DSR should be paid LMP minus retail tariff price, as customers also benefit from avoided energy costs at a retail price (King et al., 2015). However, others contend that this would be below the optimal payment since DSR entails other costs besides the opportunity cost of lost consumption. In 2016, the Supreme Court ruled in favour of the FERC for its role in regulating DSR in the wholesale markets.

c) *Research needs on the participation of demand-side resources in the capacity market*

Understanding how the designs of capacity market affect the integration of demand-side resources is critical for acquiring cost-effective EE and DSR as capacity. It is key for assessing the relationship of system needs, market potential and role of the capacity market in promoting demand-side resources. However, the literature on these issues is still limited. First, while there is seminal work on the participation of EE and DSR in the forward capacity markets of PJM and ISO-NE, such work was done prior to recent changes in the design and product definition of these two markets. Moreover, there is no similar research for the capacity markets outside the U.S. (e.g.

---

[26] Subject to a net benefit test to ensure that overall benefits of reduced wholesale energy price because of DSR is higher than the cost of dispatching it

the UK) that show an interest in integrating demand-side resources. Second, there is no dedicated research on how the capacity market could support other policy objectives apart from resource adequacy. Knowledge in this area can contribute to the debate on whether the capacity market, as a vehicle for ensuring resource adequacy, could be a primary instrument for advancing the agenda in promoting electricity use reduction and growth of the DSR market. Third, EE and DSR are related but distinct in how they deliver capacity and likely to face different drivers from regulatory or market forces. There is very limited literature on how these two demand-side resources may differ in the nature, scale and drivers of their participation in capacity auctions. Empirical research on such relationship would inform the design of integration mechanisms and a realistic assessment of the scale of contribution from demand-side resources.

2.6. Chapter summary

This chapter reviews two strands of literature key to this thesis. First, it briefly introduces the value of electricity use reduction and discusses common policy options to address the barriers for investing in electric energy efficiency (EE) measures and promoting electricity use reduction – the key role of financial incentive schemes, one area this thesis focuses on, is highlighted. Given that the novel approach of incentivising electric EE using a capacity market is first piloted through the Electricity Demand Reduction (EDR) Pilot, the policy context of electricity use reduction in the UK is also summarised. Second, the literature on electricity market liberalisation, particularly the implication for ensuring capacity adequacy and participation of demand-side resources, is synthesised. It highlights the ongoing debate on whether a capacity market would be an optimal solution to ensure capacity adequacy. It also identifies areas of literature contributions this thesis can make, which are elaborated in Chapter 8.

3 | Methodology

This chapter summarises the high-level key methodological thinking and the practical context for undertaking this research. Since each paper has its own methodology section, the intention is not to repeat the detailed discussion of research methods therein but to complement it.

This thesis draws upon case studies to answer the question of *what role a forward capacity market can play in promoting electricity use reduction*. It does this by analysing a combination of primary and secondary evidence, and assessing whether assumptions, explicitly and implicitly made by policy designs, can be substantiated empirically. As for the methodology, it is similar to evaluating a particular policy (e.g. how a policy works in achieving its objectives), although the focus herein is the high-level lesson or implication that is widely applicable to other jurisdictions. In this chapter, theory and practice of policy evaluation is reviewed for general methodological implications. Then, the use of case studies is justified and a set of criteria for choosing cases are described. Several research methods are introduced, before the relationship of the government's evaluation of the EDR Pilot and implications for this thesis are discussed.

3.1. Evaluation of energy efficiency schemes: theory and practice

For EE policy and schemes designed to achieve its objectives, evaluation serves two purposes: 1) estimating the impacts, for regulatory compliance and other reasons; and 2) understanding the process of participation and relationship to design features and outcomes, for refining the design and implementation (CPUC, 2006; Wade and Eyre, 2015b). Accordingly, two types of evaluation can be conducted, namely *impact evaluation* and *theory-based or process evaluation*. The focus of this thesis is not evaluating a single policy scheme *per se* but a general policy approach. Even so, the theoretical and practical concerns of policy evaluation provide high-level directions on the overarching approach of this thesis (Section 3.1.3).

3.1.1. Impact evaluation

Impact evaluation concerns the delivery of policy targets like energy or peak demand savings, CO_2 savings and cost-effectiveness (de la Rue du Can et al., 2014). As discussed in Chapter 4, while many electric EE programmes in the U.S. are typically evaluated for their energy savings and coincident peak savings, in Europe the focus appears to be on energy- or CO_2-savings.

Depending on scheme priorities and resources (e.g. budget), impacts can be projected based on an *ex ante* basis, or estimated *ex post* with data collected during or after scheme implementation. Methods of varying rigour levels (e.g. engineering estimates, direct metering, model simulation) can be used, based on practical considerations such as the reliability of estimate with engineering assumptions, salience of specific projects or measures to the portfolio-level savings, and resource availability (CPUC, 2006, 2010a). Net savings, adjusted from gross savings to account for free-ridership and spill-over effect, are integral for assessing the extent to which savings are 'additional' and attributable to the scheme (see Chapter 4).

3.1.2. Theory-based evaluation

Theory-based evaluation turns the unit of analysis to the *mechanisms* of policy intervention. This involves construction of policy *theories*, which articulate assumptions, hypotheses, logic and causal links of how the intervention is supposed to work, and tests them with empirical evidence (Harmelink et al., 2008; Khan et al., 2006; Pawson and Sridharan, 2009; Pawson and Tilley, 2004; Riché, 2012; White, 2009). It entails eliciting and formalising policy theories, by reviewing policy documents (e.g. guidance and regulation), collaborating with policy designers and even drawing upon theories in social science (e.g. psychology, economics) (Birckmayer and Weiss, 2000; Khan et al., 2006; Weiss, 1997). Indicators are identified and quantitative and/or qualitative evidence is collected to assess the programme theory. The process is iterative – empirical evidence is used to refine policy theories and design (Birckmayer and Weiss, 2000; Khan et al., 2006). Benefits of the theory-based evaluation are identification of 'inadequate or unnecessary' policy components, knowledge development (e.g. knowledge gap, mechanisms or factors to focus on for research) and focused evaluation activities (Birckmayer and Weiss, 2000). As discussed in Weiss (1997), two strands of theory-based evaluation are valuable. First, detailed programme theories that allow tracking of each mini-step leading to final outcomes and iterative process of testing them would help build a rich knowledge base to inform later policy designs in terms of what works in which conditions. Second, another direction is to focus on a limited set of *central* assumptions that are key for the success of policy, common across different schemes and potentially questionable. In other words, this involves testing 'macro-theoretical assumptions' across different case studies (Weiss, 1997). It contributes to the development of knowledge on whether a broad policy strategy, rather than a specific scheme tailored to the context in which it is implemented, would likely be feasible in a range of conditions – this would be valuable for policymakers considering a similar scheme with the same high-level design features.

The theory-based approach can be used for assessing whether an intervention would likely be successful based on evidence from similar schemes (i.e. prospective), whether implementation is conducive to successful outcomes (i.e. during implementation), and how the observed outcomes can be attributed to the scheme and how to improve its design (i.e. after implementation) (Leeuw, 2012; Riché, 2012). There are several approaches for articulating the policy theories, with slightly different evaluation purposes and focuses (Leeuw, 2012):

- **Realist evaluation** – this theory-based approach recognises that mechanisms (i.e. process by which target recipients 'interpret and act upon' intervention measures) and context in which scheme is carried out (e.g. socioeconomic and organisational context) can bear on the outcomes (Pawson and Tilley, 2004). The focus is on 'what works for whom, in what contexts, and how' – it reflects the possibility that the operation of scheme mechanisms may differ among groups of target recipients or geographies (Leeuw, 2012).

- **Theory of change** – it emphasises the importance of clarity about the *process* of change that a scheme aims to effect (e.g. changes in the near- and medium-term) (Weiss, 1995). The long-term policy is deconstructed into a series of necessary outcomes (Leeuw, 2012). Then near- and medium-term outputs are to be articulated to lead to these outcomes.

- **Contribution analysis** – it focuses on the causal relationship between policy intervention and the observed outcomes, to assess the contribution of a given scheme to the outcomes. It does not purport to *definitively* establish the causal link but tries to *reduce uncertainty* of the contribution of scheme to the observed outcomes using evidence (Mayne, 2001).

- **Policy scientific approach** – reconstructing logical propositions is vital for this approach. It starts with policy goals and scheme mechanisms to reformulate their causal links into ‘if-then’ propositions, and uses argumentation analysis to fill missing links in the logical argument (Leeuw, 2003). After the policy theories are constructed, different approaches can be used to evaluate them, including juxtaposing of alternative theories, triangulation using primary and secondary evidence, and existing reviews or syntheses (Leeuw, 2012).

- **Strategic assessment approach** – it focuses on how stakeholders should be grouped for reformulating policy theories, with the aim of debating between groups and synthesising assumptions, particularly where disagreement lies (Leeuw, 2003; Mitroff and Mason, 1980).

- **Prospective evaluation synthesis** – this approach focuses on the *potential* of a proposed scheme and less on ‘actual performance of existing programme’ (Leeuw, 2012). It entails construction of policy theories and context, and examination of the existing knowledge of similar schemes to gauge the likely success of the proposed scheme (Wholey, 1987). Essentially, it is ‘a prospective analysis anchored in evaluation concepts’ that aims to assess whether a successful scheme is possible, *logically*, *operationally* and *empirically* (Leeuw, 2012).

Process evaluation is a related term used mainly in the evaluation literature from the U.S. – it encompasses evaluation of the scheme design (e.g. programme theory, logic) and operation (e.g. administration and implementation) for improvement recommendations (CPUC, 2006). As noted in Birckmayer and Weiss (2000) and Suchman (1968), evaluating the quality of implementation (e.g. programme activities) is needed to determine whether the undesired outcomes are due to 'faulty' programme theory (e.g. unsound logic) or underperformance in implementation. Weiss (1997) distinguishes programme theory (i.e. mechanisms intervening between scheme provisions and outcomes) from implementation (i.e. how the scheme is carried out).

Criticisms are lodged against the programme theory-based approach (White, 2009). Although they do not discredit the use of theory-based evaluation, they highlight several key aspects of how it should be done. First, a theory-based approach is regarded as static whereas the implementation may adapt or deviate from what is supposed to be done. As argued by White (2009), it underscores the need of documenting changes in scheme design and associated learning process, and analysing why discrepancy exists in the implementation and how it relates to the observed outcomes. In a way, this points to a necessary iterative process of data analysis and theory refinement that requires the theory to be adaptable and accommodate expected or unexpected patterns. Second, unintended effects may be left out of the evaluation if the focus is on causal links constructed only based on official documents or perspectives of scheme designers. Therefore, it is important to account for different and sometimes competing programme theories and integrate unintended effects that are identified in preliminary fieldwork in the evaluation.

3.1.3. Implications for this thesis

For the methodology and research approach of this thesis, three high-level implications can be drawn from the theories and practices of evaluating EE schemes.

- **Evaluating a policy design involves explicitly constructing and examining theories, logic, causal link and assumptions behind its design features.** As set out in Chapter 1, understanding the role of a forward capacity market in promoting electricity use reduction is essentially assessing its outcomes in 1) incentivising investment of electric EE and 2) procuring it as a capacity resource. It entails deconstructing central designs of a forward capacity market, identifying the assumptions for how providing financial incentives with these central designs would help address barriers for EE investment and its participation in the capacity auctions, and assessing how these assumptions may or may not hold with empirical evidence. For schemes without much empirical evidence (e.g. on a prospective basis), it is possible to assess whether a design would be feasible, based on the articulated policy theories, assumptions and logic, and evidence from other similar schemes.

- **It is justifiable to focus on central design features or assumptions.** Although this thesis is inspired by the EDR Pilot in the UK, it focuses on its unique strategy of relying on the forward capacity market to incentivise electric EE. In other words, it is most interested in a *broad strategy* rather than the specific design details of the EDR Pilot. As discussed in Section 3.1.2, it is justifiable to focus on *central* design features or assumptions common to various schemes, with the need to analyse across case studies and assess their feasibility in a range of conditions.

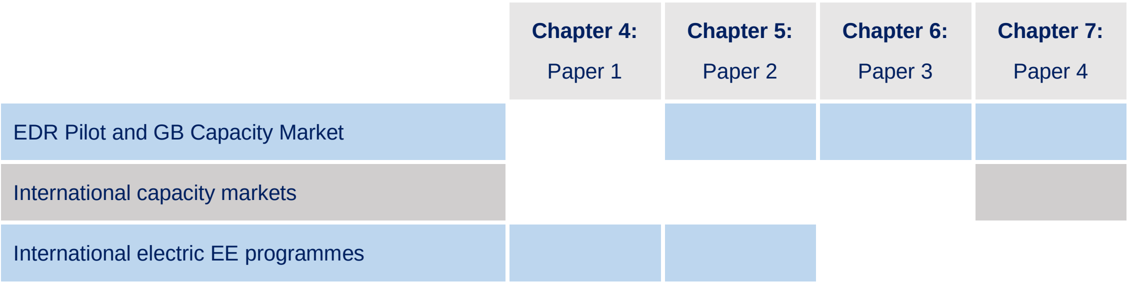
- **It is essential to understand the context.** There are two aspects. On one hand, as seen in Chapter 2, incentive schemes operate in not only the wide economic and socio-political backdrop, but also the landscape of policies for promoting electric EE. So, in comparing across case studies, a good synthesis of the wider policy context (e.g. level of ambition, provision of non-incentive support and/or other incentive schemes) is necessary. Second, for the impact evaluations, as the actual approach of evaluation is subject to a multitude of practical factors (e.g. focus on energy- or peak-savings, budget and reliability of earlier evidence), it is key to take note of the regulatory and operational framework under which the reviewed impact evaluations are produced (e.g. if a standard M&V protocol is used).

3.2. Case studies: rationale and selection

The case study is a research strategy for ‘empirical investigation’ in a ‘real-life context using multiple sources of evidence’ (Robson and McCartan, 2016; Yin, 1981). This thesis undertook three types of case studies to seek evidence for assessing the assumptions about a forward capacity market as a vehicle for promoting electricity use reduction:

- The EDR Pilot and GB Capacity Market in the UK;
- International forward capacity markets that integrate demand-side resource like EE and DSR; and
- International electric EE programmes, particularly how their financial incentive schemes are designed and their evaluation outcomes (e.g. impact and process evaluation).

As can be seen in Fig. 3-1, each empirical paper conducted different sets of case studies, reflecting the nature and requirements of research questions addressed. Moreover, specific cases may cover different jurisdictions across empirical papers. Details about specific case studies can be found in the methodology section of each paper.



	Chapter 4: Paper 1	**Chapter 5:** Paper 2	**Chapter 6:** Paper 3	**Chapter 7:** Paper 4
EDR Pilot and GB Capacity Market		🟦	🟦	🟦
International capacity markets				▨
International electric EE programmes	🟦	🟦		

Fig. 3-1. Case study categories in each empirical paper

3.2.1. Rationale for using case study as a method

The choice of case study as a methodological tool reflects three of its strengths in relation to the nature of research in this thesis. First, given the empirical focus of this research, case studies allow the analysis to utilise rich materials related to EE programme evaluation, incentive scheme design and the forward capacity market, to scrutinise quantitatively the link of peak- and energy-savings, how the savings-based approach is employed in *real-world* schemes to offer incentives, and the *actual* success of the forward capacity market in promoting demand-side resources.

Second, compared with research of a large sample size (e.g. large-N survey), the case studies 'take the descriptive-interpretive elements more seriously' and are very well suited to determining 'specific mechanisms and pathways between causes and effects', with a less focus on the relative strength of factors contributing to an outcome (Blatter, 2008). In this thesis, by examining how the residential sector responds to the EDR Pilot and how the forward capacity market integrates demand-side resources, case studies enable the analysis to go beyond quantifiable impacts (e.g. savings, project cost) and understand the mechanisms, context, processes and factors that operate to influence the outcomes of a policy scheme. In other words, a case study has an advantage of going 'deep' in analysis (Blatter, 2008) and this is valuable for investigating whether policy assumptions as embedded in the scheme design can be substantiated.

Third, even with a similar policy rationale and assumption, it is not unusual to see incentive schemes being designed differently or facing different contextual factors, across jurisdictions. By examining the difference in design and how it relates to the implementation and outcome, case studies help identify key drivers for the success of the incentive scheme and the mechanism for integrating demand-side resources in a forward capacity market. It is more than benchmarking – it is assessing central assumptions common to various scheme designs and drawing lessons widely relevant. As highlighted in Robson and McCartan (2016), the focus of multiple case studies is an 'analytic generalisation'.

There are three approaches for conducting case studies, reflecting different research goals (Blatter, 2008). *Naturalism* focuses on the practical and detailed knowledge of a phenomenon and its causal process by getting close to the case (e.g. participatory observation), whereas *positivism* aims to construct theoretical models or propositions that reflect a general objective reality. These two approaches assume the existence of a generalizable objective reality but differ in the position on how to reveal it. For naturalism, it is a process of learning and knowledge diffusion, and researchers themselves may not attempt to generalise; for positivism, it is a deliberate act to draw interpretive inference from a set of cases, at a logical, analytical or theoretical level (Yin, 2003). *Constructivism* is the third approach that does not assume an objective reality and views the case study as a 'contribution and check to a theoretical discourse', focusing on closing the gap between empirical observations and theories (Blatter, 2008). For this thesis, the position aligns more with positivism with its primary aim of understanding the role of the forward capacity market, *as a broad strategy*, in promoting electricity use reduction. While theorisation is not the main motive, the generalisation at a logical level is what this thesis aims for.

3.2.2. Criteria for selecting cases

Different types of case studies vary in their strategies for choosing cases to serve their goals (Blatter, 2008). For naturalism, an intrinsic interest, probably due to practical impacts of the case, or the possibility of accessing required materials are adequate criteria. For positivism, given its focus to generalise, the case selection should consider the position of a specific case in the wider population (e.g. how representative or statistically salient the case is, based on prior analyses) and the similarity or difference of cases to allow the cross-case analysis. For constructivism, the focus is on cases that make theoretical generalisation possible. Most/least-likely case design is used – it assumes that some cases are more important than others for testing a theory (Levy, 2008). If a prior analysis suggests that a case study fits (or does not fit) with a theory, and data is out of (or within) the prediction of the theory, the validity of theory is weakened (or strengthened). However, even for positivism and constructivism, practical considerations may well be criteria for the case selection (Blatter, 2008).

This thesis includes case studies of the EDR Pilot and the GB Capacity Market, because their design and policy assumptions are the origin of research interest in the role of the forward capacity market in promoting electricity use reduction. Given the limited empirical evidence in the UK (e.g. peak-energy relationship of electric EE measures, a savings-based approach for providing financial incentive), and the intention to draw widely applicable lessons, this thesis conducts case studies of international EE programmes, incentive schemes and the forward capacity markets that face diverse regulatory and market conditions. Several high-level criteria are used to select cases, while for each empirical paper additional criteria may be used (see Methodology sections in each paper). Criteria are applied on a balanced basis to reflect the requirements of analytical objectives and practicality in conducting research.

- **Relevance to the policy design and assumptions to be examined.** Case studies should be EE programmes that evaluate energy saving and peak demand reduction of efficiency measures, schemes featuring a savings-based approach for providing financial incentives, and the forward capacity markets integrating EE as well as DSR as capacity resource. It is to be noted that this thesis is looking for cases, not necessarily the same with the EDR Pilot but sharing some central design characteristics (Section 2.4.5). Moreover, to allow a cross-case analysis, the choice of cases should reflect diversity in regulatory and market factors that may bear on the outcomes of incentive schemes.

- **Evidence gap in literature and policy debate.** A consideration is whether the existing evidence or planned policy evaluation (Section 3.4) can adequately support the analysis. For assessing whether the forward capacity market would likely be a primary vehicle to incentivise electric EE, there is little available evidence that allowed the research to reach any sort of conclusion for the residential sector. Therefore, a case study in the UK is done to collect primary evidence for understanding the potential and barriers of using capacity market to incentivise electric EE in the residential sector.

- **Policy schemes with an established record and experience.** Selecting cases with some years of implementation, ideally with notable changes in design features, would provide examples of stable implementation or rich experience of designing and refining policy schemes. Of all the existing capacity markets, only PJM and ISO-NE have an established history of integrating electricity use reduction and these two capacity markets procure on a three-year forward basis – this is primary reason that this thesis focuses on the forward capacity market, while it considers the implication of forward procurement in interpreting the findings. These international examples complement the study of EDR Pilot and the GB Capacity Market that are novel in terms of design and implementation experience.

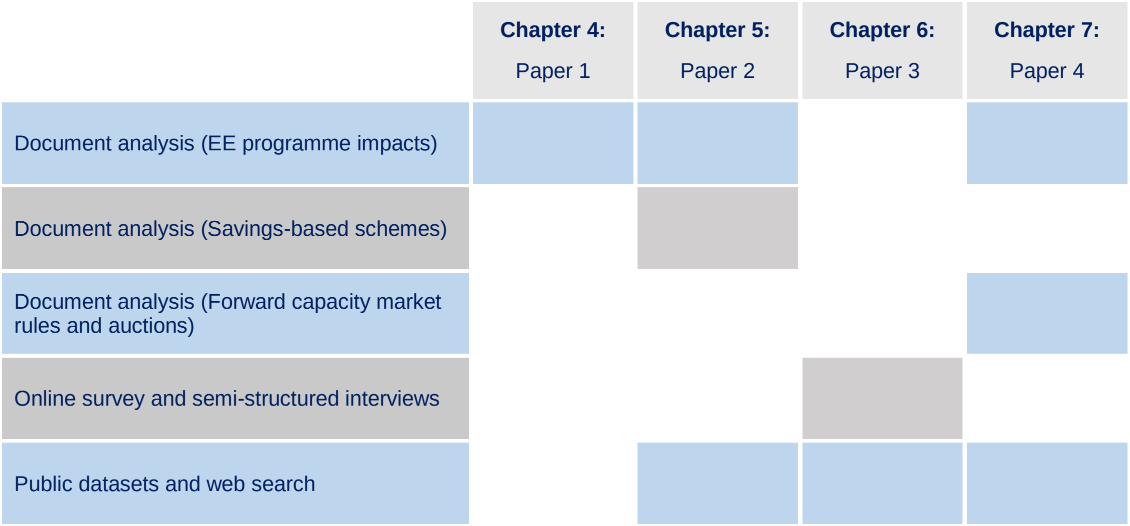
- **Availability of documentation of scheme design, outcomes and impacts.** Analysis of cases requires public access to information regarding the design of incentive scheme, its impacts of promoting electric EE projects and energy- and/or peak-savings, and for the forward capacity markets, how electricity use reduction participates in the auctions and with what outcomes. Moreover, this thesis focuses on documentation produced in English due to the language skills of the author.

- **Availability of robust and well-documented scheme evaluation.** For analysing peak-energy relationship of electric EE measures, *ex post* evaluation of coincident system peak demand reduction and energy savings at the end-use level is needed. To examine savings-based incentive schemes, the process evaluation that scrutinises programme theory, logic and implementation is a valuable resource. Therefore, incentive schemes with process evaluation are a priority in the analysis (Chapter 5).

On a balanced weighing of these criteria, this thesis ultimately conducts case studies of chosen utility EE programmes and savings-based incentive schemes in the U.S., Canada and Europe, two forward capacity markets of ISO-NE and PJM, apart from EDR Pilot and the GB Capacity Market.

3.3. Research methods

This section describes the methods employed in this thesis (Fig. 3.2).



	Chapter 4: Paper 1	**Chapter 5:** Paper 2	**Chapter 6:** Paper 3	**Chapter 7:** Paper 4
Document analysis (EE programme impacts)	■	■		■
Document analysis (Savings-based schemes)		■		
Document analysis (Forward capacity market rules and auctions)				■
Online survey and semi-structured interviews			■	
Public datasets and web search		■	■	■

Fig. 3-2. Summary of key methods in each empirical paper

3.3.1. Quantitative and qualitative methods

A combination of quantitative and qualitative methods is used. At a high level, the approach of policy evaluation this thesis draws upon, particularly theory-based evaluation, emphasises the use of multiple qualitative and quantitative methods, which are complimentary to each other, to scrutinise scheme's processes and outcomes (Pawson and Tilley, 2004; White, 2009). The balance is more of a matter of practicality – it depends on the hypothesis or assumption to be tested and the data availability (Pawson and Tilley, 2004).

Considering this, the mixed methods reflect the nature of analysis and the type of evidence needed in papers. First, quantitative data is essential for specific lines of inquiry, including the peak-energy relationship of electric EE measures, the project type and outcome of savings-based incentive schemes, and the contribution of EE in the capacity auctions. It is chiefly because of the research objective to *quantify* how well peak savings align with energy savings and what role a savings-based incentive scheme and the forward capacity market can play in terms of promoting electric EE and electricity use reduction.

Second, qualitative methods (e.g. interview, document analysis) are indispensable – in fact, they can complement the quantitative analysis in allowing mechanisms and processes behind the scheme design, and factors bearing on the implementation and outcomes, to surface (Pawson and Tilley, 2004). These ‘building blocks’ of a policy scheme are, in many cases, difficult to quantify. However, if they are well understood, it would help assess the assumptions made in policy design, the extent to which outcomes relate to the scheme mechanisms, and the role the forward capacity market – in a general sense based on its core designs – *can* play rather than necessarily what it *has* played. In a way, qualitative methods help contextualise quantitative evidence to assist data interpretation, and ‘tease out’ the central ‘storyline’ for argument. Moreover, qualitative methods like semi-structured interviews are flexible in nature, achieving the balance between hypothesis-driven evidence search and a scope for internalising new concepts, ideas and opinions as the research progresses.

Third, a combination of quantitative and qualitative methods makes it possible to tri-angulate information. This is particularly important for semi-structured interviews where interviewees may provide opinions based on personal experience or general impression and it may not be possible or time-efficient to seek backing of evidence, particularly quantitative data.

3.3.2. Primary and secondary evidence

The evidence and materials used for assessing policy assumptions come from primary and secondary sources. The consideration for choosing either type of evidence is whether the existing datasets, reports or other evidence would be adequate to support the analysis and argument in this thesis. In a way, it is intended to capture the efficiency benefits of utilising secondary data like time- and labour-savings as well as less intrusion for participants when compared with the first-hand data collection (K.McGinn, 2008).

Primary data and evidence is collected via an online survey and semi-structured interviews, for studying what role a forward capacity market can play in incentivising electric EE investment in the residential sector of the UK. The primary reason is that neither existing literature nor the planned EDR evaluation covers the potential of the forward capacity market or its savings-based approach in promoting electric EE investment in households. Therefore, a case study on social housing in the UK is conducted using online survey and semi-structured interviews, the results of which are then extrapolated to the residential sector overall.

A variety of secondary sources are extensively utilised, like the evaluation reports of obliged EE programmes by utilities, participation guidance for incentive schemes, datasets or government statistics on electricity use and the penetration of efficient equipment or measures, and auction results of the forward capacity markets. Choice of specific secondary sources depends on several factors, including the relevance to research questions and analytical aspects of case studies, and quality and accessibility.

3.3.3. Online survey

Survey research is a common method for collecting information in a systematic way, which accommodates qualitative and quantitative data (Julien, 2008). An online survey is administered via Survey Monkey to gauge awareness and participation of social housing providers in the EDR Pilot, chiefly because no information is publicly accessible on organisations that have taken part in the application or auction. Another objective is collect quantitative information on the activities, funding arrangements, key decision-making factors and barriers for electric EE projects – this serves as benchmark for understanding the existing context for electricity use reduction, and key trends and practices of investing in electric EE before the EDR Pilot. Results of the survey are exported into Microsoft Excel spreadsheet for analysis and visualisation.

At the end of survey, respondents are invited to take part in a semi-structured interview over phone for an in-depth discussion about the design of EDR Pilot and incentive schemes in general (see below). Responses to the survey are reviewed and key discussion topics may be incorporated into the topic guide for semi-structured interview. By including questions that can be standardised in a separate survey and using them to adjust the interview topic guide, it allows the conversation to be more targeted, for testing hypotheses and gathering information, and more productive.

3.3.4. Semi-structured interviews

Semi-structured interviews differ from structured interviews in that the range of responses to a given question is not fixed, although the researcher still maintains some level of control of topics to cover in the interview (Ayres, 2008; Brinkmann, 2008). Researcher typically prepares a topic guide based on the research question and tentative conceptual model or hypothesis, while there is flexibility to adapt what and how to ask depending on respondents' answers (Morgan and Guevara, 2008).

Respondents for semi-structured interviews are recruited from the online survey and 'cold calls' with follow-up email correspondence. The primary objectives of these interviews are to: 1) allow the interviewer to have a deep discussion with respondents on previous and planned electric EE projects, regarding the process and decision-making, based on survey responses if applicable; and 2) explore how respondents perceive the EDR Pilot and its design, and any barriers they may expect or encounter in participation. In other words, the focus is on the mechanisms, procedure and context in which electric EE improvement is undertaken, and how the EDR Pilot is seen by social housing providers. If no survey is completed before the interview, questions as in the survey are incorporated in the interview topic guide. For coming up with relevant questions to encourage a meaningful conversation, semi-structured interviews require preliminary information gathering, observation and literature review. The online survey serves as an important basis for identifying key areas of questions, and when the survey questions are incorporated into an interview, the topic guide (e.g. what to ask and in which order) is adapted based on respondent's answers. More details about the topic guide of semi-structured interviews can be found in Chapter 6 and its appendix.

Interviews are recorded after respondents give their oral consent for doing so. Then interviews are transcribed and NVivo is used to code and analyse them. Ethical permission is granted by the Central University Research Ethics Committee of the University of Oxford for the online survey and semi-structured interviews.

3.3.5. Document analysis

Many documents and reports are reviewed to retrieve the evaluated savings impact of electric EE programmes by end-use, to synthesise the regulatory context for electric EE, and the design and impact of incentive schemes with a savings-based approach, and to examine the mechanism and outcome of the forward capacity market integrating demand-side resources. These documents and reports are available from the websites of utilities or third parties that are obliged with targets for EE improvement, market regulator overseeing the utility EE obligation, and system operators that run the forward capacity markets or their independent market monitor.

In analysing these documents and reports, given the large volume of content, the focus is to synthesise and collate information and data that is central to assessing the policy assumptions. It is a hypothesis-driven approach. For example, for savings-based incentive schemes, documents reflecting the policy objectives and programme theory (e.g. guidance setting out the rationale of scheme, process evaluation) are analysed. The focus is on the objectives shared by schemes, how they are translated into design features (e.g. target customers, incentive structure), and drivers and barriers of participation in relation to design, rule and market conditions. As for the evaluation of savings, consistency in the M&V protocol or procedures is one consideration for deciding whether to include specific evaluation reports. If possible, for a given EE programme or incentive scheme, documents and reports in multiple years are reviewed and compared to identify any changes in design, implementation and outcomes, as well as tri-angulating.

3.3.6. Datasets and web search

To complement document analysis and improve the efficiency of information retrieval, public datasets are utilised. These datasets are regularly updated by the government agency or reputable organisations that research or coordinate the EE policy development. In some cases, especially for identifying the savings-based incentive schemes, web search (e.g. websites of utilities, ‘grey literature’) is also used alongside literature review to gather information for regions not covered by the established datasets.

Several major datasets used by this thesis are briefly introduced here. The Database of State Incentives for Renewables and Efficiency (DSIRE) is queried for EE incentive schemes affecting electricity use and using a savings-based approach, in the U.S. DSIRE is operated by the Clean Energy Technology Centre of North Carolina State University, with funding from the Department of Energy. For each scheme, the description about the design, type and structure of incentive and other provision (e.g. technical assistance) is reviewed and classified based on design features as discussed in Chapter 5. The Regional Energy Efficiency Database (REED) provides a consistent platform for reporting savings, expenditure and funding sources of utility EE programmes in the Northeast and Mid-Atlantic of the U.S. Moreover, for the case study on potential of the EDR Pilot in the residential sector, statistics for electricity use (e.g. the Digest of United Kingdom Energy Statistics (DUKES), Energy Consumption in the UK), efficiency ratings (e.g. Household Energy Efficiency National Statistics) and housing stock, ownership and conditions (e.g. English Housing Survey, Scottish House Condition Survey, Dwelling stock estimates for Wales, Local Authority Housing Data, Directory of Social Landlords in Scotland and Statistical Data Return for English private social housing providers, etc.) are retrieved from the websites of government and devolved administrations. Methodology sections of each empirical paper discusses how these datasets are used, which are cited accordingly.

3.4. Evaluation of the EDR Pilot led by the government

A multi-year evaluation project is commissioned to assess the design and outcome of the EDR Pilot, and the feasibility of integrating EE into the GB Capacity Market. While efforts were made earlier to seek collaboration in research, practical constraint means that data and information related to the Pilot (e.g. information on participants, their bids and proposed projects) cannot be shared, unless it is included in the published evaluation reports. Moreover, the evaluation project involves interviewing organisations that applied to the EDR Pilot or simply registered interest. The focus of evaluation was claimed to be on C&I participants and this thesis was requested to avoid overlaps with their planned research. While these challenges have led the research plan to be revised multiple times and affected the progress, this thesis finally managed to find a 'research space' that is independent of the government evaluation and complementary to it. In a practical sense, particularly for the policy in the UK, two contributions are made to the study of EDR and its unique approach of providing financial incentives. First, by focusing one case study on how the residential sector takes up the funding opportunities of EDR, this thesis complements the government evaluation for considering the role the EDR can play in incentivising electric EE in different customer segments. Second, by drawing upon international experiences with the forward capacity markets and savings-based incentive schemes, which are richer than those in the UK, it synthesises implications about scheme design, and regulatory and market conditions to inform the next stage of policy refinement to better support electric EE. The interim evaluation report of EDR Pilot was released in February 2017 (BEIS, 2017a), which contains findings on its outcomes (e.g. types of participants and projects), implementation, and drivers and barriers for participation. These findings and conclusions are incorporated in the analysis of this thesis to support discussion and interpretation, in a similar way as document is analysed.

3.5. Limitation in methodology

The methodology has two major limitations. First, the EDR Pilot in the UK is the first scheme in the world attempting to use the forward capacity market as a primary vehicle for providing financial incentives to support electric EE. In terms of comparing across cases, this thesis does not have other cases that *exactly* replicate the policy or regulatory intention. As a research strategy, it focuses on key designs and assumptions, and whether the expected mechanisms would likely be feasible, based on a combination of primary evidence and outcomes from schemes with *similar* design features. While this general approach is justifiable, caution needs to be taken in interpreting findings and drawing policy implications.

Second, for comparing with international schemes, this thesis utilises secondary sources like process evaluation reports. To a large extent, it relies on document analysis. However, as noted in Prior (2008), documents are ‘conduits of communication…that contain meaningful messages’. In other words, they reflect the priorities and perspectives of authors in conducting research and presenting findings. While practical constraints (e.g. large number of programmes, work done by independent consultants, lack of access to all materials related to a scheme) make it impossible to interview researchers producing these documents, the potential difference in research aims or priorities means that not all analytical aspects this thesis is interested in are covered by the secondary source. Alternatively, it is also possible that data may not be presented in a way that is directly usable to this thesis. These constraints can limit the scope of inquiry.

3.6. Chapter summary

This chapter sets out high-level methodological thinking to complement the methodology sections in each paper. Theory and practice of evaluating the EE policy provides guidance to this thesis – assessing the role of the forward capacity market in promoting electricity use reduction involves examining the assumptions, logic and mechanisms behind the policy design, and how empirical data, primary and secondary, can support them. Given the primary interest in a broad strategy of using the forward capacity market to promote electricity use reduction, it is justifiable to focus on central designs and assumptions. Moreover, it is important to consider the context in which a scheme is implemented. This chapter also introduces and justifies key methods employed, such as case study and mixed methods to collect qualitative and quantitative evidence through an online survey, semi-structured interviews, and document and dataset analysis.

4 | Paper 1: Seasonal relationship of peak demand and energy impacts of energy efficiency measures – a review of evidence in the electric energy efficiency programmes

This paper starts by examining the first research question of 'whether the forward capacity market can be a primary vehicle to give incentives and drive investment in electric EE', which is the focus of Papers 1-3. Paper 1aims to address the first hypothesis (H1) or policy assumptions as set out in Chapter 1, i.e. whether peak savings and energy savings are well aligned in terms of giving incentives to electric energy efficiency investment and achieving policy objectives.

4.1. Abstract

While energy efficiency programmes traditionally focus on energy savings, there is also a policy interest in their impact on system peak demand. Examples include demand-side management, integrated resource planning and recent developments to integrate energy efficiency into forward capacity markets. However, there is only limited research on the relationship between peak demand impacts and overall energy savings from efficiency measures, although this relationship can have important bearings on efficiency programmes. This paper reviews utility efficiency programmes in nine jurisdictions in North America, and analyses how the seasonal peak-energy relationship differs between commercial and industrial (C&I) and residential sectors, among efficiency measures. In terms of the seasonal difference in peak demand impacts, these programmes show that residential lighting and residential water heating can deliver greater peak savings in weekday early evening winter peak periods. By contrast, C&I lighting and residential appliances make higher peak savings in weekday afternoon summer peak periods. Seasonal difference is more significant in lighting, especially residential lighting, than other measures. The evidence from North America also suggests that space cooling in both sectors and C&I lighting may well make greater peak savings relative to non-peak impacts than other measures during summer peak periods, while in winter peak periods, residential lighting can achieve greater peak savings relative to non-peak impacts. This review highlights the significance of regional electricity use patterns along with climatic and regulatory conditions, and indicates how further research may contribute to appropriate electricity demand reduction programme design and monitoring regimes in particular regions.

Keywords: energy efficiency, electricity, peak demand, energy saving, seasonal electricity demand

4.2. Introduction

Energy efficiency is at the heart of policy efforts to reduce total electricity use. With the increasing concern of electric system reliability, it is also seen as a cost-effective resource alternative to generation to contribute to the system capacity adequacy (Anthony and Foley, 2014). In parts of the US, there is some history for procuring energy efficiency, in the demand-side management (DSM) programmes and utility resource acquisition, for addressing the peak demand problem (e.g. Hopper et al., 2009; Nowak et al., 2011). Several regional system operators (e.g. CAISO, 2013) are exploring the ways of integrating energy efficiency into system planning and operation. In Europe, while traditionally the objective of energy efficiency is energy saving (e.g. ECEEE, 2013; Rosenow and Galvin, 2013), there is an emerging interest in the impacts on system peak demand. Of particular note is the Electricity Demand Reduction (EDR) pilot in the UK, which was launched in 2014 to test the feasibility of promoting electric efficiency through the Great Britain (GB)[27] Capacity Market (DECC, 2014a). The EDR pilot offers financial incentive for replacing less efficient electrical equipment. The financial incentive is given on the project basis via a market-wide forward auction, which is open to various efficiency measures, as long as the eligibility and measurement and verification (M&V) requirements are met. As the EDR

---

[27] Great Britain (GB) is made up of England, Scotland and Wales, but does not include the other member nation of the United Kingdom, Northern Ireland

pilot is interested in the possible integration with the GB Capacity Market (DECC, 2013a), the financial incentive is based on projects' verifiable *reduction in system peak demand*[28], not their impacts on total electricity use.

The reduction in system peak demand and total electricity use represents two distinctive aspects of energy efficiency. While efficient electrical equipment can generally reduce electricity use, the reduction may not necessarily coincide with the highest system demand, thus having only limited impacts on the capacity resource requirement. This may be true for equipment tending to be used outside system peak period, or in a season different from the one with the highest system demand in a year (e.g. space cooling in a winter-peaking system).

Examining the relationship between peak demand and energy savings of efficiency measures is important for electric energy efficiency programmes. Firstly, for programmes required to meet both peak demand- and energy-saving targets, the peak-energy relationship of efficiency measures can be one factor among others influencing the technology composition in programme design or the actual achievement of programme targets (e.g. CLC, 2012; CLC, 2013). Secondly, if programmes could claim some financial remuneration for their impacts on system peak demand (e.g. participation in a forward capacity market), the relative share of efficiency measures with notably different peak-energy relationship in the technology composition may have financial implications. Thirdly, for the EDR pilot in the UK, the amount of total energy saving associated with the coincident peak demand[29] reduction of energy efficiency projects is a vital indicator of success for the policy whose ultimate goal is also to reduce electricity use and carbon emissions (DECC, 2013a). Analysis of the peak-energy relationship also provides a basis for comparing the EDR pilot with other energy efficiency policies, in terms of cost-effectiveness in promoting energy savings.

---

[28] System peak demand period is defined as 4pm-8pm of non-holiday weekdays between November and February

[29] Coincident peak demand is the electricity demand occurring during the system peak demand periods

A number of studies have investigated the peak demand impacts of energy efficiency. While Kushler et al. (2002) summarised the estimates of peak demand and energy reductions for the selected ‘reliability-focused’ programmes in California, it did not conduct further analysis on the peak-energy relationship for these different programmes. York et al. (2007) reviewed ten programmes using *ex post* methods to estimate the peak demand impacts, and found that the ratio of peak demand reduction to energy-savings (MW/GWh) varied ‘by a factor of around 5’ among the chosen programmes. Meanwhile, a growing number of programme evaluation studies have started reporting the peak demand impact of energy efficiency, even at the level of individual measures. However, there is a lack of comprehensive analysis on the peak-energy relationship, especially how it may differ between seasons, efficiency measures and sectors in which these measures are applied.

This study analysed the peak-energy relationship of several efficiency measure categories, by reviewing 60 recent evaluation or verification reports for 33 selected utility energy efficiency programmes or portfolios in the US and Canada. These programmes or portfolios are from nine jurisdictions and cover a range of efficiency measures and sectors. Section 4.3 introduces the background of energy efficiency as a resource to reduce system peak demand. Section 4.4 describes how energy efficiency programmes are identified for case studies and defines a metric for analysing the peak-energy relationship. Section 4.5 summarises the framework for evaluation or the approach to estimating the peak demand and energy impacts of selected programmes. Section 4.6 and 4.7 present and discuss the results of analysis on the peak-energy relationship. Section 4.8 provides some concluding remarks.

4.3. Electric Energy Efficiency: A system resource for reducing peak demand

Ample evidence exists to show the potential of efficiency measures in reducing peak demand. For example, Nadel et al. (2000) showed the sizeable peak demand impacts (nearly 30GW in mid-1990s) from utility energy efficiency and load management programmes between 1992 and 1998 in the US. They also suggested large potential of specific programmes, like commercial and industrial (C&I) lighting and residential HVAC[30], in slowing the projected peak demand growth. Kushler and Witte (2003) found that 'accelerated, enhanced and targeted' efforts to acquire energy efficiency had been successful in reducing the system peak demand in the 2001 summer. The *ex post* evaluation results of programmes reviewed by York et al. (2007) also demonstrated that energy efficiency could deliver 'measurable, significant peak demand savings'.

A cost-effectiveness test for efficiency resources is a common practice, for designing and evaluating programmes, in determining whether the benefits (e.g. peak demand reduction and energy savings) are greater than the costs (e.g. Kushler et al., 2012; NAPEE, 2008). Molina (2014) reviewed utility energy efficiency programmes in 20 states of the US between 2009 and 2012, and found that the average cost was 2.8 cents/kWh. This is only a fraction of the cost of supply solutions, and this low-cost level remains even as the efficiency procurement target is higher. Results of forward capacity market auctions in PJM and ISO New England (ISO-NE) demonstrated that demand resources like energy efficiency could help save capacity costs (Gottstein and Schwartz, 2010).

There is a history of actively procuring electric efficiency as a system resource. In the US, after the start of utility energy efficiency programmes in 1970s, there emerged the ideas of DSM, which includes energy efficiency and load management, and integrated resource planning (IRP) whereby demand-side and supply-side resources are considered together to fulfill the long-term utility resource needs (e.g. Eto, 1996; Lamont and Gerhard, 2013; Schweitzer et al., 1991). While electric sector restructuring weakened the regulatory and financial basis for DSM and IRP, the concerns of electric system reliability, rising costs and environmental concerns have re-prioritised efforts to achieve greater energy efficiency since the early 2000s (e.g. Barbose et al., 2013). This is marked by the establishment of Energy Efficiency Resource Standards (EERS) in half of the

---

[30] Heating, ventilation and air conditioning

states in the US as of 2014, to oblige utilities or independent programme administrators to achieve mandatory energy efficiency targets, with some of them requiring *all* cost-effective efficiency to be procured (CEC, 2013; Downs and Cui, 2014; Gilleo, 2014; Palmer et al., 2013b). The EERS in many states specify goals for both peak demand- and energy-savings (Kushler et al., 2006). In other regions (e.g. Ontario and China), utility energy efficiency programmes are also required to achieve particular peak demand- and energy-saving targets (OEB, 2013; Plunkett et al., 2012).

Moreover, efficiency resources can also help address local system reliability issues (Neme and Sedano, 2012). For instance, in 2006, the Vermont Public Service Board directed Efficiency Vermont to intensify the efficiency resource acquisition in targeted geographic areas, so as to reduce the peak demand and defer the transmission and distribution (T&D) upgrades (Navigant, 2011). The Rhode Island Energy Efficiency and Resource Management Council and National Grid developed a framework in 2010-2011 for utilities to assess the potential of cost-effective ‘non-wires alternatives’ including energy efficiency in the ‘distribution planning’ (Anthony and Foley, 2014).

An emerging area is the participation of energy efficiency in forward capacity markets, which use forward auctions to acquire capacity resources to meet forecasted peak demands. Resources clearing forward capacity auctions receive regular payment in return for the commitment to deliver contracted amount of generation capacity or demand reduction during specified peak periods (Jenkins et al., 2011). In the US, the forward capacity markets of ISO-NE and PJM allow energy efficiency to compete against generation and other demand-side resources (e.g. demand response) in the auction. There are several requirements for participation, including minimum peak demand reduction, forward planning and more rigorous M&V for evaluating peak demand reduction (e.g. ISO-NE, 2015a; ISO-NE, 2015b). In the ISO-NE Forward Capacity Market (FCM), the contribution of energy efficiency has increased greatly from 655 MW in the first auction in 2008 to almost 2 GW in the 8th Forward Capacity Auction in 2014, representing around 6% of all the capacities cleared (ISO-NE, 2014a). Many utility energy efficiency programmes within the service areas of ISO-NE or PJM have bid into the respective forward capacity markets, with the capacity payments contributing less than 15% of the total funding for many of these programmes[31] during 2011-2013 (NEEP, 2015). However, the costs of M&V activity in compliance with the capacity market requirements are high, thus reducing the amount actually available to support the efficiency portfolio (Neme and Cowart 2014).

As noted in Vine (2008) and York et al. (2007), the impact evaluation of efficiency programmes focused on energy savings rather than peak demand impacts, due to factors including technical issues, costs associated with additional metering requirement and programme priority. However, a number of trends are changing the landscape for peak savings evaluation, including the growing interest in efficiency as a system resource, market opportunities (e.g. participation in capacity market) that value the accurate estimation of peak demand impacts, rigorous M&V protocols, and roll-out of advance metering (Michals and Titus, 2006).

4.4. Methodology

4.4.1. Identification of energy efficiency programmes

This review has focused on utility energy efficiency programmes, largely because they are typically subject to regulatory impact evaluation (e.g. energy and/or peak demand savings) and cover a range of efficiency measures in different sectors. In principle, as some efficiency resources participate in forward capacity market, it is possible to compare their verified capacity performance with the energy savings for analysing the peak-energy relationship. However, detailed evaluation reports for their capacity performance and energy impacts at the end-use level are not available. While most of the efficiency resources cleared in forward capacity auctions are part of the utility energy efficiency programmes (Neme and Cowart, 2014), it should be noted

---

[31] Electric energy efficiency programmes in Connecticut, Maryland, Massachusetts, New Hampshire and Rhode Island. Capacity payments for the electric energy efficiency programmes in Vermont are channelled to its natural gas energy efficiency programmes.

that regulatory programme evaluation might be different from capacity performance evaluation (see Section 4.5 for example).

Several criteria are applied in identifying the programmes for case studies. Firstly, only those involving installation or replacement of electric efficiency measures[32] are included. In other words, programmes such as fuel switching, demand response and behavioural projects are excluded. Secondly, peak demand and energy impacts should be evaluated with *ex post* methodologies, and peak demand impacts should be coincident with system peak period. Thirdly, the evaluation reports should be publicly accessible and have reasonably adequate details on the evaluation methodology (e.g. approach for estimating impacts, relevant evaluation protocol) and definition of system peak period. They should also detail the peak demand and energy impacts of various measure categories or even individual measures, which can be reported at the level of efficiency portfolio[33] or programme. Finally, a number of practical considerations (e.g. consistency between programme years in terms of evaluating and reporting impacts[34]) also determine whether to include the evaluation reports for particular programme years.

A total of 60 recent evaluation or verification reports are identified, covering 33 utility energy efficiency portfolios or programmes of nine jurisdictions in the US and Canada (see Appendix). While this review began with an international search, it found that programmes evaluating both peak demand and energy impacts are more common in North America, while energy efficiency programmes in Europe tend to focus primarily or solely on their energy impacts. Most of the programmes included herein are evaluated by their respective regulatory authorities or appointed third parties. These nine jurisdictions have also established regulatory requirements for some kind of cost-effectiveness test to ensure the benefits of efficiency programmes are greater than costs.

---

[32] Including operational optimisation in some measure categories

[33] Portfolio-level evaluation reports report the energy and peak demand impacts for all of their energy efficiency programmes

[34] For example, in the Conservation and Demand Management (CDM) programmes funded by Ontario Power Authority, *the EM&V Protocols and Requirements 2011-2014* defines the peak demand period differently from before it was introduced

While some evaluation reports (e.g. portfolios of Massachusetts and Vermont) detailed the peak demand and energy impacts by broad measure categories, others reported savings for individual measures. For the latter, this review re-grouped individual measures into broad measure categories (e.g. lighting, water heating) to facilitate comparison. This study also combined the impacts of residential programmes with those of low-income programmes, and only made distinction between C&I and residential programmes. Moreover, as most of the evaluation reports reported *net*[35] peak demand and energy impacts, this study used *net* savings consistently unless it was not possible to do so, in which case *gross* savings are used instead. As the practice of estimating *net* impacts varies across states (Kushler et al., 2014), this may influence the inclusion of individual measures in a particular category and thus its average peak-energy relationship, especially if the difference in peak-energy relationship is significant between individual measures.

4.4.2. Analysis of peak-energy relationship – introducing the Peak-Energy Ratio (PER)

In order to analyse the peak-energy relationship for various measure categories, this study defines a Peak-Energy Ratio (PER) to calculate the ratio of coincident peak demand savings (MW) and annual electricity energy savings (MWh) divided by the hours in one year:

$$PER_i = \frac{Coincident\ Peak\ Demand\ Savings_i}{Annual\ Electricity\ Energy\ Savings/8{,}760}$$

where *i* indicates the season (e.g. summer or winter) for which coincident peak demand savings are evaluated. If there are evaluation reports for the same portfolio or programme for multiple years, for each measure category, coincident peak demand savings and annual energy savings are summed separately before calculating the PER.

---

[35] Net impacts refer to those that can be directly attributed to the programme effects (e.g. discounting free-rider and/or free-driver effects from gross impacts).

The benefit of PER is its simplicity for presenting and comparing the peak-energy relationship between different measure categories. As a ratio, PER characterises the savings of efficiency measures in system peak periods *relative* to those in non-peak periods. In other words, a larger PER *does not* imply higher peak demand impacts. It simply means that if measures achieve the same energy savings, the one with larger PER is better at reducing peak demand; or if measures reduce the same peak demand, the one with smaller PER can deliver higher energy savings.

4.4.3. Limitation of study

There are a few limitations to this review. Firstly, the number of evaluations focusing on both peak demand and energy savings is still limited. Even when they do, many studies do not report impacts at the level of measure categories. These factors limit the ability of this review to conduct cross-regional comparison or draw conclusion on the peak-energy relationship for various efficiency measures. In other words, the evidence from the utility energy efficiency programmes reviewed herein may not be directly applicable to other regions (e.g. Europe). Secondly, the evaluations vary in their methodologies in estimating peak demand and energy impacts. While it is impossible for this study to analyse how such difference may have affected the evaluation outcomes, however, these evaluations have, to the extent possible, used locally specific and regularly updated evidence or on-site M&V (e.g. metering and measurement). As discussed in Section 4, the Technical Reference Manual (TRM), which establishes algorithms and assumptions for estimating peak demand and energy impacts, is used widely in programme evaluation and usually updated regularly. Some programmes follow rigorous protocols such as the International Performance Measurement and Verification Protocol (IPMVP). Thirdly, PER reflects an average level of peak-energy relationship for a broad measure category. As the peak-energy relationship can vary significantly between individual measures or the locations where these measures are applied (e.g. NMR, 2007), PER may be influenced by the actual measure inclusion in programme. Since the reporting of impacts for individual measures is not common, this review could only undertake analysis for broad measure categories.

4.5. Evaluation of Energy and Peak Demand Impacts

This section summarises the framework or approach for evaluating utility energy efficiency programmes in the nine jurisdictions covered herein. While British Columbia is a winter-peaking system, many others experience their highest peak demand in summer. However, a number of programmes in Connecticut, Maine, Rhode Island, Ontario and Vermont evaluate the coincident peak demand impact of efficiency measures for both winter and summer. Table 4-1 summarises the definition of system peak periods in the nine jurisdictions. For regions covered by ISO-NE FCM, the peak demand period is differentiated between on-peak and seasonal peak hours – on-peak hours are pre-determined, and seasonal peak hours are when actual system hourly load on non-holiday workdays is at least 90% of the most recent '50/50' System Peak Load Forecast[36] for summer or winter. However, most of the programmes covered by ISO-NE FCM evaluated the peak demand impacts during on-peak hours, unless otherwise noted. The peak period in Hawaii is defined as 5p-9pm on weekdays and given its climatic characteristics, PERs calculated for measures in the Hawaii portfolio are treated as summer PERs.

Table 4-1. Definition of peak period in the evaluation studies

Regions	System Peak Periods
Massachusetts[1] **Vermont[1]** **Rhode Island[1]** **Maine[1]** **Connecticut[1]**	On-Peak Hours Summer – 1pm-5pm of non-holiday weekdays for June-August Winter – 5pm-7pm of non-holiday weekdays for December-January Seasonal Peak Hours Summer – real-time system hourly load ≥ 90% of the most recent '50/50' system peak forecast for June-August Winter – real-time system hourly load ≥ 90% of the most recent '50/50' system peak forecast for December-January
California[2]	Summer – 2pm-5pm during the three-consecutive weekday period containing the weekday temperature with the hottest temperature of the year
Ontario[3]	Summer –1pm-7pm of weekdays for June-August Winter – 6pm-8pm of weekdays for December-January
British Columbia[4]	Winter – 5pm-7pm of weekdays
Hawaii[5]	5pm-9pm of weekdays

[1] Defined in consistence with ISO New England Forward Capacity Market
[2] Based on the programme evaluation reports for 2006-2008, 2009 and 2010-2012
[3] Based on the Ontario Power Authority EM&V Protocols
[4] Based on the BC Hydro Demand Side Management Milestone Evaluation Summary Reports
[5] Based on the Hawaii Energy Annual Reports for Programme Years 2009-2012

---

[36] Load forecast is based on probability. A '50/50' load forecast means that there is a 50% chance for the actual load to exceed the forecast.

Peak demand impacts typically represent the average savings in electric load during relevant system peak periods. If prescribed assumptions are used for estimating peak demand savings (i.e. without metering), adjustments are typically made to the reduction in the sum of individual maximum demand from installed and operational equipment (i.e. reduction in connected loads). This involves the application of adjustment factors (e.g. diversity and coincidence factor[37]) determined from primary load research to represent the percentage of reduction in connected loads coincident with system peak period.

4.5.1 Massachusetts

The annual programme evaluation uses *the Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures* (TRM), which establishes methods and assumptions (e.g. baseline and average annual hours-of-use) for estimating peak demand and energy impacts (MEGEEPA, 2011, 2012b). The TRM utilises Massachusetts-specific data or alternative evidence (e.g. industry and manufacturing data, best evidence from neighbouring regions) to establish assumptions. In estimating coincident peak demand savings, the TRM uses coincidence factors[38] for summer and winter peak periods to adjust the connected loads. Such factors are based on prior evaluation results, secondary evidence (e.g. research to inform the evaluation) or common assumptions, and follow the peak period definition and methodology of ISO-NE FCM (MEGEEPA, 2011, 2012b). For custom C&I projects, the TRM also sets out guidance for project-specific evaluation, which may involve engineering analysis, on-site metering and energy model simulation.

The TRM corresponds with individual programme years. The Plan Version is filed before the start of programme year for tracking progress and the Report Version, which is updated to integrate new evidence or reflect changes (e.g. new measures), is used to adjust the programme

---

[37] Diversity factor represents the ratio between the highest simultaneous peak demand reduction for a population of specific equipment and the reduction in connected loads. Coincidence factor is the percentage of the highest simultaneous peak demand reduction coincident with system peak period.

[38] In the Massachusetts TRM, coincidence factor is defined differently as it is the product of coincidence factor and diversity factor.

impacts for reporting to the Department of Public Utilities. The administrators of energy efficiency programmes identify the needs for TRM update, while the TRM Coordinating Committee facilitates the update process. Since 2010, the TRM Report Version has been filed with annual programme reports (MEGEEPA, 2011). In terms of M&V studies, an evaluation plan subject to annual review and update needs to be approved by the Massachusetts Energy Efficiency Advisory Council, and 'consideration will be given to regional EM&V activities and FCM requirements' (MEGEEPA, 2009, 2012a).

4.5.2. California

The California Energy Efficiency Evaluation Protocols is the primary framework for planning, undertaking and overseeing the evaluation of energy efficiency programmes delivered by the four largest investor-owned utilities (IOUs) (CPUC, 2010a). It is based on *the California Evaluation Framework* released in 2004, and has established minimum allowable methods for estimating energy and peak demand impacts at different rigour levels ('Basic Level' and 'Enhanced Level'), by adhering to the IPMVP (CPUC, 2006). At the Basic rigour level, simple engineering model (IPMVP Option A) and weather-normalised annual consumption analysis are acceptable for energy evaluation, while secondary data like allocation factors and load profiles (from Database for Energy Efficiency Resources or other sources[39]) can be used to estimate the coincident peak demand impacts as a function of energy impacts. At the Enhanced Level, multi-variable regression analysis, calibrated building energy simulation (IPMVP Option D), retrofit isolation measurement (IPMVP Option B) and experimental design involving treatment and non-treatment groups are allowed for energy evaluation. Estimating peak demand impacts at the Enhanced Level requires primary evidence including interval or time-of-use electricity usage data[40], spot or continuous metering data[41] and experimental design.

---

[39] Include the California Energy Commission forecasting model utility end-use load profile or other studies. However, their use needs the 'review and approval through the evaluation planning review process'.

[40] Regression analysis can be used to account for weather and other variables

[41] Used with IPMVP Option B or Option D

The Joint Staff of California Public Utilities' Commission (CPUC) and California Energy Commission will assign evaluation rigour levels to measures, based on the contribution and uncertainty of savings, whether prior evaluation can reliably reflect the current programme reality and future prospects of specific measures (CPUC, 2006, 2010b). The evaluation prioritises 'high impact measures'[42], and at the rigour level chosen by the Joint Staff, employs methods like on-site metering, simulation analysis and engineering analysis to estimate peak and energy savings. This review covers the evaluation for the 2006-2008, 2009[43] and 2010-2012 programme cycles. The 2006-2008 evaluation is the first time consistent methods and measure-level datasets from IOUs were used.

4.5.3. Efficiency Vermont

Efficiency Vermont is the first statewide energy efficiency utility in the US to promote cost-effective efficiency for residential and business customers. It is appointed by the Public Service Board of Vermont, which sets performance goals (e.g. for peak demand and energy impacts) for Efficiency Vermont. The annual reports, which detail peak demand and energy impacts for the Efficiency Vermont portfolio, are products of the annual saving verification by the Vermont Department of Public Service (DPS). Given the tight timeframe for annual verification, the key objective is to confirm that calculation, assumption and methodology are correctly applied in the savings claim of Efficiency Vermont. It is largely based on desk-based review of project files and programme tracking data (e.g. WHEC, 2012b; WHEC, 2013). This entails random sampling and review of C&I and multi-family projects based on the information provided by Efficiency Vermont, and a comprehensive review of prescriptive residential efficiency measures based on the Vermont TRM and recent evaluation studies. The methodologies and assumptions in the TRM are reviewed and updated annually using the work of Technical Advisory Group (DPS, 2009b,

---

[42] Measures constituting more than 1% of IOU-claimed energy savings

[43] The evaluation for 2009 bridge funding period draws upon the results of 2006-2008 programme evaluation

2011). Besides annual saving verification, market studies are also conducted to assess baselines for future evaluations and new energy efficiency opportunities (DPS, 2009a, b, 2011).

As Efficiency Vermont bids its electric efficiency portfolio into ISO-NE FCM, its coincident peak demand impacts are subject to the FCM M&V requirements, which are more rigorous than the annual saving verification. A review of the FCM evaluation reports (WHEC, 2010, 2012a) indicates that custom C&I projects are sampled for evaluating their peak demand savings with appropriate M&V (e.g. on-site metering), while residential measures are reviewed based on the TRM and recent research efforts. In sampling the custom C&I projects, the same sampling plan based on peak demand impacts was employed for the saving verification and the FCM evaluation for programme years prior to 2012 (e.g. WHEC, 2012b). However, for programme year 2012, the sampling strategy for saving verification has focused on annual energy savings, to better align with the primary goal of Efficiency Vermont to reduce energy use (WHEC, 2013). For this reason, the peak demand impacts determined from annual saving verification might be different from those estimated by the FCM evaluation.

4.5.4. Hawaii

Hawaii Energy Conservation and Efficiency Programmes are subject to annual verification of their peak demand and energy savings, by an independent contractor appointed by the Hawaii Public Utilities Commission. This involves an annual review of the Hawaii Energy Efficiency Programme TRM, sampling verification of installation and operation of qualified measures, and validation that the approved TRM has been correctly and consistently applied in calculating the programme savings (e.g. Evergreen Economics, 2014). In other words, saving verification relies heavily on the TRM, while engineering analysis for sampled custom measures is also conducted. The annual review and update of TRM takes into account a number of factors, including new measures in programme, changes in baseline due to updated efficiency codes and standards, new studies and third-party review based on field research and verification (e.g. Hawaii Energy, 2013; Leidos Engineering, 2013).

4.5.5. Other energy efficiency programmes

The methodologies for evaluating peak demand and energy savings of other programmes are summarised in the Appendix. Different approaches have been applied for various measure categories and sectors, with some of them in compliance with IPMVP and ISO-NE FCM M&V requirements. Some jurisdictions draw upon the leading evaluation practice in other regions and internationally. For example, BC Hydro follows *the California Evaluation Framework* in evaluating the impacts of its DSM programmes (e.g. BC Hydro, 2014).

4.6. Relationship between Peak Demand and Energy Savings

The Appendix details the PERs for various efficiency measures in the programmes or portfolios reviewed. Fig.4-1 shows the range and median of PERs for measures commonly applied in residential and C&I sectors. However, some measures contribute more to the impacts of programmes than other measures over the years covered in the review. For example, for the portfolios of Massachusetts, Hawaii, California and Efficiency Vermont, efficient lighting has contributed at least 50% and 70% of the peak demand and lifetime energy savings[44] respectively in the residential sector. In the C&I sectors, while efficient lighting contributes at least 45% of peak demand and lifetime energy savings, other measure categories like HVAC and industrial process also deliver considerable impacts as well. This section reports the PERs for different measure categories, while Section 4.7 discusses the variance of PERs within and between measure categories, and what this means for the peak-energy relationship.

---

[44] Lifetime energy savings refer to the amount of energy savings specific measures can accrue over their operational lifetime

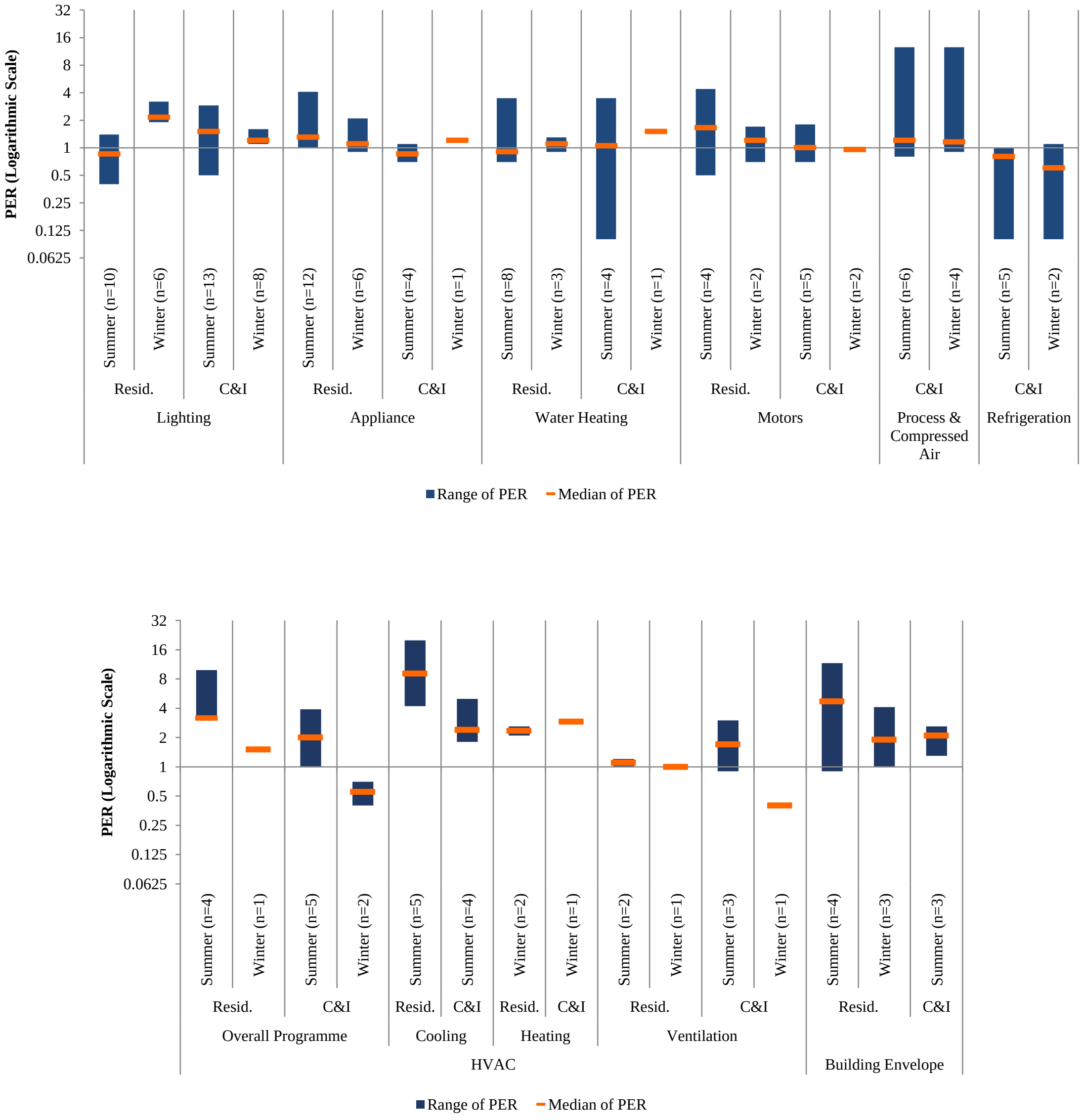


Fig.4-1 Range and median of Peak-Energy Ratio (PER) for energy efficiency measure categories

Source: Own calculation based on review of evaluation reports

4.6.1. *Lighting*

A total of twenty-three efficiency portfolios or programmes have reported the impacts of efficient lighting measures (e.g. CFLs, LEDs and lighting control). The peak demand impacts of lighting measures vary between seasons, and the pattern of such variance seems to differ between sectors. For residential lighting, the PER is higher for winter (1.9-3.2) than summer (0.4-1.4). In programmes reporting the peak demand impacts of residential lighting in both seasons (i.e. Maine, Efficiency Vermont and Connecticut), the PER for winter is nearly twice that for summer.

For C&I lighting measures, by contrast, the PER is generally higher in summer (1.2-2.9) than winter (1.1-1.6), except the two custom lighting programmes in Rhode Island (PERs of 0.5-0.7 and 1.2-1.4 for summer and winter respectively). Moreover, as seen from programmes in Efficiency Vermont and Connecticut, the seasonal difference in PER for C&I lighting is less significant than that for residential lighting.

Another observation is that for the same season, residential and C&I lighting demonstrate a distinctive peak-energy relationship. With the exception of Hawaii where summer PER for C&I lighting (1.2) is marginally lower than that for residential lighting (1.3), most regions see a notably higher summer PER for C&I lighting. In some of them (e.g. Massachusetts and Connecticut), the summer PER for C&I lighting is more or less twice that for residential lighting, while the difference is more notable in Ontario. The winter PER for residential lighting, by contrast, is 50-75% higher than that for C&I lighting in the programmes of Efficiency Vermont, British Columbia and Connecticut.

This study also identifies the evaluation for some other specialised lighting measures, the PERs of which are not reflected in Fig.1. For example, the seasonal LED programme of BC Hydro aimed to promote LED lights in the holiday lighting market. The winter PER for seasonal LED is at a very high level of 42.3, largely due to its concentrated use during winter peak period for the short holiday season (BC Hydro, 2009). The winter PER for LED traffic lights in British Columbia is 1.0.

4.6.2. Appliances

This category covers a range of appliances (e.g. refrigerators, washing machines, dishwashers) used in residential and C&I sectors. Twelve portfolios or programmes have reported the impacts of improving appliance efficiency. For residential appliances in most of the programmes, the range of summer PER is 1.0-1.7, while the winter PER falls within 0.9-1.2. However, some programmes show notably high PERs. For example, regarding dehumidifiers used in households, the Residential Appliance Rebate Programme in Maine and the Residential Consumer Energy Efficiency Programme in Ontario show a summer PER of 2.0 and 4.1 respectively. Moreover, the Consumer Electronics Programme in British Columbia also demonstrates a winter PER of 2.1 for efficient televisions.

For appliances used in C&I sectors, the evaluation results from California, Hawaii, Efficiency Vermont and Ontario show the summer PER range of 0.7-1.1, while the Efficiency Vermont portfolio demonstrates a winter PER of 1.2. Moreover, the California portfolio also shows a summer PER of 0.7[45] for plug-load measures in commercial sectors.

4.6.3 Water Heating

Efficiency measures for water heating in the programmes reviewed include hot water pipe wrap, low-flow showerheads and insulation for electric water heating, heat pump water heaters and so forth[46]. Eight portfolios or programmes have included the impacts of water heating measures in their evaluation reports. For residential water heating measures, the summer PER for most of the programmes falls within 0.7-1.5, while a high summer PER of 3.5 is found in the California portfolio. The winter PER for the programmes in Efficiency Vermont and Connecticut shows a range of 0.9-1.3. From the limited evidence from these two regions, another observation is that the winter PER is moderately higher than the summer PER.

For water heating measures in C&I sectors, the summer PER for Hawaii and Efficiency Vermont portfolios shows a range of 1.0-1.1, while particularly low and high values are seen for Massachusetts (0.1) and California (3.5) respectively. Only the Efficiency Vermont portfolio has

---

[45] Not included in Fig.1

[46] Fuel switching measures such as solar water heating are not considered in this review

reported the winter peak savings of C&I water heating measures, with the winter PER being 1.5, which is higher than the summer PER (1.1).

4.6.4. Motors

Efficient motors (e.g. variable speed drive) can be applied in HVAC (e.g. furnace or central air conditioning) and non-HVAC (e.g. refrigeration and pool pump) systems. For efficient motors in residential HVAC systems, two programmes in Ontario show a summer PER range of 2.5-4.4, while the Variable Speed Furnace Motor Programme for households in British Columbia demonstrates a winter PER of 1.7. For HVAC motors in C&I sectors, the Hawaii portfolio shows a summer PER of 1.0, while the Energy Conscious Blueprint Programme in Connecticut exhibits a PER of 0.7 for summer and 0.9 for winter.

For residential motor measures not marked as used in HVAC systems, the portfolio of Efficiency Vermont shows a PER of 0.8 for summer and 0.7 for winter, while that of Massachusetts demonstrates a summer PER of 0.5. By contrast, for non-HVAC motors in C&I sectors, the portfolios of Massachusetts, Hawaii and Efficiency Vermont observe a higher summer PER range of 0.8-1.8, while that of Efficiency Vermont also shows a winter PER of 1.0.

4.6.5. C&I Process and Compressed Air

Five portfolios or programmes in Massachusetts, California, Efficiency Vermont, Rhode Island and Connecticut have reported the savings of efficiency measures in C&I processes and compressed air, with the range of summer and winter PER being 0.8-1.8 and 0.9-1.3 respectively. However, in the Small Business Energy Advantage Programme in Connecticut, one custom compressed air project for an automobile shop exhibits a high PER of 12.6 for summer and winter.

4.6.6. C&I Refrigeration

The portfolios of Massachusetts, California, Hawaii and Efficient Vermont demonstrate the summer PER of 0.8-1.0, while the Efficient Vermont portfolio also reports a winter PER of 1.1. By contrast, the Small Business Energy Advantage Programme in Connecticut demonstrated a low PER of 0.1 for summer and winter, largely because the efficient refrigeration measures in this programme are mostly control measures used mainly during off-peak period (Cadmus, 2009).

4.6.7. Heating, Ventilation and Air Conditioning (HVAC)

Depending on programme offerings, measures covered in the HVAC category may include more efficient air conditioning equipment, space heating (e.g. heat pump) and ventilation measures. For the HVAC category overall, the portfolios of Massachusetts, Hawaii and Efficiency Vermont demonstrate a summer PER range of 3.0-3.3 and 1.0-2.0 for residential and C&I sectors respectively, while that of California shows high summer PERs for residential (9.9) and C&I sectors (2.5). As for winter PER, the portfolio of Efficiency Vermont indicates a PER of 1.5 and 0.7 for residential and C&I HVAC measures respectively. In addition, a custom C&I HVAC programme in Rhode Island demonstrates a PER of 3.9 for summer and 0.4 for winter.

For space cooling measures, the portfolios of Hawaii and Efficiency Vermont see a summer PER range of 4.2-7.8 and 1.8-2.3 for residential and C&I sectors respectively. Programmes in Connecticut and Ontario also show larger summer PERs for residential air conditioning equipment (9.1-20.0) and C&I space cooling measures (2.5-5.0). These findings seem to suggest that summer PER for residential space cooling measures, especially air conditioning, is higher than that for C&I measures.

For space heating measures, however, the evidence is more limited. In the Efficiency Vermont portfolio, the winter PER for residential space heating measures (2.6) is slightly lower than that for C&I measures (2.9). Heat pumps may provide space heating in winter (e.g. replacing electric heaters) and space cooling in summer. For example, the Residential Geothermal Heat Pump Programme in Connecticut shows a PER of 2.1 for winter and 1.2 for summer, for a typical household.

In terms of residential ventilation measures, the Efficiency Vermont portfolio shows a PER of 1.0 for summer and winter, while that of Hawaii indicates a summer PER of 1.2. For C&I ventilation measures, by contrast, the summer and winter PER for the Efficiency Vermont portfolio are 1.7 and 0.4 respectively, while the portfolio of Hawaii exhibits a summer PER of 0.9. However, the High Performance New Construction Programme for the commercial sector in Ontario sees a notably higher summer PER (3.0) for its agribusiness ventilation measures.

4.6.8. Building Envelope

The energy and peak demand impacts of building envelope measures (e.g. insulation) are related to the use of electric equipment (e.g. electric space heating) and are typically estimated using energy simulation models. Only six portfolios or programmes in Massachusetts, California, Hawaii, British Columbia and Connecticut report savings from building envelope measures.

For residential building measures, programmes in Massachusetts, California and Connecticut show a wide variance in the summer PER (0.9-11.6), with the highest and lowest observed in California and Connecticut. Similarly, for winter PER, programmes in British Columbia and Connecticut exhibit a wide range (1.0-4.1).

For non-residential building measures, the portfolios of Massachusetts, Hawaii and California demonstrate a summer PER range of 1.3-2.6. Moreover, in Massachusetts and California, the summer PER for C&I building measures (2.1-2.6) is lower than that for residential building measures (3.0-11.6).

4.7. Discussion

4.7.1. Variance of the PERs within measure category

As shown in Fig.4-1, for the same season, PERs for a particular measure category in a given sector tend to vary across efficiency portfolios or programmes. The difference between the highest and lowest PERs for the same season seems more remarkable in some measure categories (e.g. summer residential lighting) than in others (e.g. winter lighting).

Several reasons may explain the *within-category* variance. Firstly, a category covers a range of individual efficiency measures, which may demonstrate different peak-energy relationship. For example, there is evidence in some TRMs (e.g. Hawaii Energy, 2013; MEGEEPA, 2013) that PERs may differ, to a varying degree, among individual measures of the same category or for the same measure applied in different locations. Since PER only considers the *average* peak-energy relationship, to the extent that such difference in PER between measures is significant, the relative share of various measures may influence the overall PER for a particular portfolio or programme. In fact, the heterogeneity among portfolios or programmes in terms of design and implementation, and target population and locations in which efficiency measures are applied implies that the relative share of measures can differ between portfolios or programmes.

Secondly, as PER essentially reflects the usage pattern of efficiency measures, its variance may somehow reflect the difference in how a particular measure is used among geographical regions. While it is beyond the scope of study to elucidate fully such relationships, there was some evidence highlighting regional differences in usage pattern. For a specific measure, its adjustment factor (i.e. coincidence and diversity factor) and average hours-of-use (HOU), which are applied to the connected loads for calculating peak demand and energy savings respectively, influence the PER. In general, the higher the adjustment factor and/or the lower the HOU, the higher the PER would be. In the case of residential lighting, the average daily HOU and winter adjustment factor[47] estimated for a programme in Maine are 2 and 0.184 respectively (Cadmus, 2012), while a recent metering study for Massachusetts, Connecticut and Rhode Island estimated these two factors to be within 2.6-2.8 and 0.16-0.17 (NMR, 2014). In British Columbia at a higher latitude, the BC Hydro Residential Lighting Programme in 2012 evaluated the average daily HOU and winter adjustment factor to be 2.6-3.2 and 0.311-0.394 (BC Hydro, 2014), leading to a greater winter PER. Moreover, NMR (2014) shows that even within the same region (e.g. New York), the average daily HOU and winter adjustment factor for residential lighting may differ notably between districts and lead to different PERs.

Thirdly, the evaluation itself may be one factor influencing the within-category variance. A representative sample is important for understanding the ‘average’ pattern of use for a particular measure. However, for some measures, especially those less commonly applied, there may be only a limited sample size in a particular energy efficiency programme. For example, the Small Business Energy Advantage Programme of Connecticut in 2007 has only one project involving compressed air measures (Cadmus, 2009). The National Grid Custom Lighting Programme of Rhode Island in 2008 shows a much lower summer PER for its C&I lighting measures than other programmes. This is largely due to the dominance of savings from a parking garage site that reduces its lighting during summer weekday afternoons (KEMA, 2009). However, this usage pattern is unlikely to be widely applicable in the C&I sector. Moreover, some of the evaluation studies used secondary evidence (e.g. load profile for a particular measure) from other regions in estimating impacts (e.g. OPA, 2014). Depending on the local relevance of such secondary evidence, this may be a factor among others contributing to difference with similar programmes in the same region, if these programmes use local evidence (e.g. metering measurement) in their evaluation.

---

[47] Adjustment factors applied to the connected loads to estimate coincident peak demand impacts in winter peak periods

4.7.2. Difference in the PERs between measure categories

Even with the variance *within* measure category, it is still possible to make meaningful observations on how the peak-energy relationship may differ between measure categories. For one thing, the jurisdictions covered in this study are diverse in their climatic conditions and efficiency programme characteristics, thus reducing the bias in analysis. Moreover, while the peak period is defined differently across jurisdictions, it typically occurs in the weekday afternoon of summer[48] or the weekday early evening of winter. Hence, observations made herein may be more or less relevant to regions with similar peak periods. However, as reflected in Fig.4-1 and Appendix, the evidence is stronger for some measure categories (e.g. lighting, appliance and water heating) and summer peak period. For other categories, particularly motors, ventilation and building envelope, the limited evidence together with the variance of PER makes it difficult to identify the peak-energy relationship.

Firstly, the seasonal pattern of PERs is diverse among measure categories. For a particular measure in a given sector, as the same annual electricity energy saving is used for calculating PERs for summer and winter, the seasonal difference of PER reflects that of peak demand impacts and thus the usage pattern. As shown in this study, residential lighting has a higher PER in winter, while C&I lighting tends to have a higher summer PER. The higher winter PER of residential lighting means a greater proportion of connected loads tend to be 'on', thus leading to larger peak demand impacts, during winter as opposed to summer peak periods. For many C&I sub-sectors (e.g. offices or retail) that are more likely to be open on weekday afternoons rather than evenings, it is reasonable to expect higher peak demand impacts from lighting measures in the summer peak period of weekday afternoons.

As for other measures, residential water heating demonstrates greater peak demand impacts in the winter peak period, whereas residential appliances tend to deliver higher peak savings in

---

[48] With the exception of Hawaii

the summer. However, the seasonal difference in PER for these measure categories is less significant than that for lighting. For C&I water heating and appliances, by contrast, the Efficiency Vermont portfolio shows greater peak savings in the winter peak period. Regarding HVAC measures, the Efficiency Vermont portfolio demonstrates that the summer PER of residential space cooling (7.8) is greater than the winter PER of residential space heating (2.6), while the summer PER of C&I space cooling (2.3) is moderately lower than that winter PER of C&I space heating (2.9). However, the review does not find evidence to support the applicability of this observation in other regions.

Secondly, even for the same season, PERs for a particular measure category may differ between residential and C&I sectors. For example, residential lighting tends to demonstrate lower summer PER than C&I lighting. To explain this pattern, there is some evidence in Massachusetts (MEGEEPA, 2013) that HOU and adjustment factors for estimating the summer PER of lighting are higher in C&I than residential sectors. In other words, lighting in C&I sectors is used for more hours annually on average than in homes, and is more likely to be ‘on’ during summer peak periods. Yet, compared with the difference in HOU between residential and C&I sectors, the difference in adjustment factors is more pronounced, leading to a lower summer PER for residential lighting. The efficiency portfolio in Hawaii is an exception, where the summer PER of residential lighting is moderately higher than that of C&I lighting. This is due to the fact that although HOU and adjustment factors are higher in C&I than residential sectors, the difference between these two sectors in adjustment factors is less than that in HOU (Hawaii Energy, 2013). One possible explanation is the difference in peak period definition – in Hawaii, the peak period is early evening when households start putting on lights and some non-residential customers reduce their lighting use.

As for efficient appliances, the portfolios of Hawaii, Efficiency Vermont and California, and programmes in Ontario show higher summer PER for residential appliances than those used in C&I sectors. In the Efficiency Vermont portfolio and programmes in Ontario, the summer PER of residential appliances is only up to 18% higher than that of C&I appliances. However, the Hawaii and California portfolios demonstrate more significant difference, with the summer PER for residential appliances 50% and 143% higher, respectively, than that for C&I appliances. Moreover, on HVAC measures overall, the portfolios of Massachusetts, Hawaii, Efficiency Vermont and California see a higher summer PER in their residential than C&I programmes. In fact, the portfolios of Hawaii and Efficiency Vermont, and five programmes in Connecticut and Ontario suggest that summer PER for residential space cooling may well be significantly higher than that for C&I space cooling.

Thirdly, compared with non-HVAC measures, some HVAC measures, particularly space cooling, tend to be associated with markedly higher PERs. In the summer, while PERs for measures like lighting, water heating, appliance and C&I processes and refrigeration are below 2 in most of the portfolios and programmes, space cooling may well demonstrate a PER considerably larger than 2. This is largely in agreement with the general account that air conditioning has ‘lower energy savings’ but higher peak demand impacts (CLC, 2011). In the winter, the Efficiency Vermont portfolio exhibits PERs of 2.6 and 2.9 for residential and C&I space heating respectively, while the Residential Geothermal Heat Pump Programme in Connecticut shows a winter PER of 2.1 for heat pumps. These winter PERs are notably greater than that for appliance and water heating measures, although the limited evidence does not prove whether this pattern applies to other regions as well.

These above observations suggest that some measures can achieve greater savings during system peak period *relative* to those during non-peak period. This will depend on the characteristics of measures (e.g. usage pattern), where they are applied and the specific electricity system (e.g. summer- or winter-peaking). While the evidence reviewed is limited, it appears that residential and C&I space cooling measures, and C&I lighting can make greater peak impacts relative to non-peak savings than other measure types, for summer peak period of weekday afternoon. As for winter peak period of early weekday evening, residential lighting may well deliver greater peak savings relative to non-peak impacts than many other measure categories.

4.7.3. Implications for energy efficiency programmes and policy

By lowering peak demand, electric efficiency measures can reduce capacity requirements and create financial savings for utilities and the whole system. For customers, however, the benefits of energy efficiency measures mainly come from energy savings, unless they are subject to time-based retail tariffs[49]. In programmes with goals for peak demand *and* energy savings, the diversity of peak-energy relationship (as reflected by PERs) among measures can influence the achievement of these goals. For instance, in the Residential Cooling and Heating Equipment Programme 2010 of Cape Light Compact, greater customer uptake of efficient heat pump and air conditioning measures, which tend to deliver greater peak savings relative to non-peak impacts, resulted in the programme achieving much higher peak impacts but moderately lower energy savings (and non-peak savings) than the planned impacts (CLC, 2011). Similarly, in the programme planning, the peak-energy relationship among measures may be one factor influencing the make-up of measures to be supported by specific programmes.

Where the EDR pilot in GB is concerned, differences in PER between seasons and measure categories mean that an exclusive focus on peak demand impacts may entail risks for energy savings. The peak period for the EDR pilot is 4pm-8pm of working weekdays between November and February. *If* the PER patterns shown above are more or less relevant to GB, to deliver the same amount of peak savings, measures with higher winter PER (e.g. residential lighting) may not result in as much energy saving as those with lower winter PER (e.g. residential appliances and C&I lighting). The 'if' is a crucial consideration: the *actual* energy impacts of the EDR pilot will depend on the mix of measures eventually supported and their specific peak-energy

---

[49] Time-based retail tariffs (e.g. time-of-use tariffs) charge different rates depending on when electricity use occurs. By lowering electricity demand (e.g. through energy efficiency) during high price hours, which are typically system peak hours, customers can reduce the electricity expenditure.

relationship in GB. Given the possible regional difference in usage pattern as discussed in Section 6.1, the evidence from North America as reviewed herein may not be directly applicable to GB or other regions. This underlines the need for more research on usage pattern and peak-energy relationship of efficiency measures, especially where the energy efficiency programmes have traditionally focused on energy savings. Moreover, for individual efficiency projects, energy saving is an important factor determining the project payback, although it is peak demand impact that influences the level of financial support potentially available from the EDR pilot. If projects can deliver the same amount of energy savings but different peak demand reductions (e.g. lighting projects with the same HOU but different operating schedules), the financial support from the EDR pilot can influence their business case or even financial viability.

The EDR pilot offers an example of a wider phenomenon. While the evaluation of efficiency programmes traditionally focuses on energy saving, there is a growing interest worldwide in reliably and cost-effectively estimating peak savings of efficiency measures. This review shows that a variety of M&V approaches (e.g. engineering analysis based on deemed parameters, metering measurement or model simulation) are used to estimate the peak demand impacts, and some jurisdictions are following IPMVP and established evaluation frameworks (e.g. ISO-NE FCM M&V). For standard measures, it is possible to estimate the peak savings by using secondary evidence (e.g. TRM) that is locally specific and regularly updated, even for the purpose of complying with the M&V requirements in capacity market (WHEC, 2010, 2012b). For custom or other measures, complex M&V including metering study or energy model simulation may be necessary, which typically involves sampling the efficiency measures or projects.

The EDR pilot allows deemed savings[50] and three metered approaches[51], based on IPMVP, for estimating peak savings. Deemed savings are based on the estimated unit reduction in load of

---

[50] Can only be used for lighting, lighting controls, motors & variable speed drives, process chiller, heating controls, retail display cabinets, and professional refrigerated storage cabinets.

[51] Partial measurement, full measurement with sub-metering and full measurement with total building metering

efficiency measures, number of measures, and hours these measures are ‘on’ during the peak period. It is necessary that the pilot evaluate not only whether its M&V requirements are adequate in making reliable estimates of peak savings, but also the cost-effectiveness of undertaking necessary M&V, given its importance for the attractiveness and viability of policy design for peak demand reduction.

4.8. Conclusion

This review has analysed the relationship between peak demand and energy impacts of several common energy efficiency measures through a review of 60 recent *ex post* evaluation or verification reports of utility energy efficiency programmes in nine jurisdictions of the USA and Canada. While there is considerable variance in the peak-energy relationship for the same measure category among programmes and the evidence is limited in some places, it is still possible to draw some conclusions on the seasonal peak-energy relationship for different measures and sectors, and on likely research priorities.

In terms of the seasonal difference in peak demand impacts, this study shows that residential lighting and residential water heating can achieve greater peak savings in winter weekday early evening peak periods, whereas C&I lighting and residential appliances appear to deliver higher peak savings in summer weekday afternoons. However, the seasonal difference is more significant in lighting, especially residential lighting, than other end-uses. Moreover, there is evidence suggesting that residential and C&I space cooling measures, and C&I lighting can make greater peak impacts relative to non-peak savings than other measure types, for summer peak period of weekday afternoon. As for winter peak period of early weekday evening, residential lighting may well deliver greater peak savings relative to non-peak impacts than many other measure categories.

These observations from a limited number of programmes, above all, highlight the complicated peak-energy relationship of energy efficiency measures that can have important bearings on efficiency programmes, especially those required to achieve both peak and overall energy saving targets. They also indicate a risk to energy savings from the EDR and comparable programmes that offer financial support to efficiency projects based on their peak demand impacts only. It is important for such pilots to look at the usage of project measures during non-peak hours, and at the potential influence of a focus on peak savings on project design.

Given the peak saving potential of energy efficiency, an interesting area for further research is the effect of more efficient equipment in specific conditions on the loads that can provide demand response. While more efficient equipment will tend to reduce loads and their potential for demand response, this study strongly suggests that such impact may be more significant in one season than others, with some end-uses more than with others, and that it will differ according to regional patterns of demand. There is a case for further research on how energy efficiency may affect the potential for demand response at different times of day and year, especially if the use of demand response is not limited to reducing demand in peak hours but for helping with system balancing in other periods as well. Finally, it will be of great value to establish how energy efficiency may find difficulty in shifting, or increasing the capacity for demand response from efficiency, as when building insulation can assist users in being more flexible with their use of HVAC.

Appendix: PERs of Energy Efficiency Measures in the Selected Efficiency Portfolios and Programmes

Portfolios/Programmes	Region	Year	PER_S	PER_W	Key Notes on Evaluation
Residential Lighting	MA	2010-12	0.8	n/a	*The Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures* (TRM) establishes methods, assumptions and evidence sources for estimating peak demand and energy impacts of efficiency measures, and guidance of project-specific evaluation for custom C&I projects. The TRM is reviewed and updated annually to incorporate new evidence from evaluation studies.
Residential HVAC	MA	2010-12	3.3	n/a	
Residential Appliance	MA	2010-12	1.1	n/a	
Residential Water Heating	MA	2010-12	0.9	n/a	
Residential Building Envelope	MA	2010-12	3.0	n/a	
Residential Motor	MA	2010-12	0.5	n/a	
C&I Lighting	MA	2010-12	1.6	n/a	
C&I HVAC	MA	2010-12	1.0	n/a	
C&I Water Heating	MA	2010-12	0.1	n/a	
C&I Building Envelope	MA	2010-12	2.1	n/a	
C&I Refrigeration	MA	2010-12	0.8	n/a	
C&I Process & Compressed Air	MA	2010-12	1.4	n/a	
C&I Motor	MA	2010-12	0.8	n/a	
Residential Lighting	CA	2006-12	1.2	n/a	*The California Energy Efficiency Evaluation Protocols*, which was established in 2006, is the framework for evaluating energy efficiency programmes delivered by the four largest investor-owned utilities. It adheres to *the International Performance Measurement and Verification Protocol* (IPMVP) and sets out minimum methodological requirements for evaluation studies. The Joint Staff of California Public Utilities' Commission and California Energy Commission will assign evaluation rigour levels to measures, based on the contribution and uncertainty of savings, specific programme conditions and reliability of previous studies.
Residential HVAC	CA	2006-12	9.9	n/a	
Residential Appliance	CA	2006-12	1.7	n/a	
Residential Water Heating	CA	2006-12	3.5	n/a	
Residential Building Envelope	CA	2006-12	11.6	n/a	
C&I Lighting	CA	2006-12	1.7	n/a	
C&I HVAC	CA	2006-12	2.5	n/a	
C&I Appliance	CA	2006-12	0.7	n/a	
C&I Plug-loads	CA	2006-12	0.7	n/a	
C&I Water Heating	CA	2006-12	3.5	n/a	
C&I Building Envelope	CA	2006-12	2.6	n/a	
C&I Refrigeration	CA	2006-12	1.0	n/a	
C&I Process	CA	2006-12	1.0	n/a	
Residential Lighting	HI	2009-12	1.3	n/a	Annual verification of the peak demand and energy savings of the Hawaii Energy Conservation and Efficiency Programmes involves annual review of the Hawaii Energy Efficiency Programme TRM, sampling verification of the installation and operation of measures, and validation that the approved TRM has been correctly and consistently applied. The review of the TRM will consider a number of factors, including new measures in programme, changes in baseline due to updated codes and standards, new evidence from evaluation or field studies.
Residential HVAC	HI	2009-12	3.0	n/a	
Space cooling	HI	2009-12	4.2	n/a	
Ventilation	HI	2009-12	1.2	n/a	
Residential Appliance	HI	2009-12	1.2	n/a	
Residential Water Heating	HI	2009-12	1.5	n/a	
C&I Lighting	HI	2009-12	1.2	n/a	
C&I HVAC	HI	2009-12	1.5	n/a	
Space cooling	HI	2009-12	1.8	n/a	
Ventilation	HI	2009-12	0.9	n/a	

Portfolios/Programmes	Region	Year	PER_S	PER_W	Key Notes on Evaluation
Motors	HI	2009-12	1.0	n/a	
C&I Appliance	HI	2009-12	0.8	n/a	
C&I Water Heating	HI	2009-12	1.0	n/a	
C&I Building Envelope	HI	2009-12	1.3	n/a	
C&I Refrigeration	HI	2009-12	1.0	n/a	
C&I Motor	HI	2009-12	1.8	n/a	
Residential Lighting	VT	2006-13	1.1	2.0	Annual saving verification by the Vermont Department of Public Service entails random sampling and review of C&I and multi-family projects based on the information provided by Efficiency Vermont, and a comprehensive review of prescriptive residential efficiency measures based on the Vermont TRM, which is updated annually, and recent evaluation studies. The evaluation of peak demand impacts for ISO-NE FCM typically involves sampling and rigorous M&V approach (e.g. appropriate IPMVP options) for custom C&I projects, and review of the TRM and recent research efforts for prescriptive residential measures.
Residential HVAC	VT	2006-13	3.0	1.5	
Space cooling	VT	2006-13	7.8	0.5	
Space heating	VT	2006-13	1.1	2.6	
Ventilation	VT	2006-13	1.0	1.0	
Residential Appliance	VT	2006-13	1.0	1.1	
Residential Water Heating	VT	2006-13	0.8	1.1	
Residential Motor	VT	2006-13	0.8	0.7	
C&I Lighting	VT	2006-13	1.5	1.3	
C&I HVAC	VT	2006-13	2.0	0.7	
Space cooling	VT	2006-13	2.3	0.4	
Space heating	VT	2006-13	0.7	2.9	
Ventilation	VT	2006-13	1.7	0.4	
C&I Appliance	VT	2006-13	0.9	1.2	
C&I Water Heating	VT	2006-13	1.1	1.5	
C&I Refrigeration	VT	2006-13	0.8	1.1	
C&I Process	VT	2006-13	0.9	1.3	
C&I Motor	VT	2006-13	1.1	1.0	
Residential Lighting	BC	2002-12	n/a	2.6	Engineering analysis based on survey and load profile
Residential Seasonal LED	BC	2003-09	n/a	42.3	Engineering analysis based on survey and load profile
Residential Refrigerator Buy-Back	BC	2003-12	n/a	1.0	Engineering analysis based on survey and hours-of-use
Residential Appliance	BC	2008-10	n/a	1.1	Engineering analysis based on survey and load profile
Residential Consumer Electronics - TV	BC	2010	n/a	2.1	Engineering analysis based on survey and load profile
Residential ENERGY STAR Window	BC	2008-09	n/a	1.9	Model simulation based on end use survey and weather data
Residential Variable Speed Furnace Motor	BC	2003-07	n/a	1.7	Engineering analysis based on supply-side and market surveys
LED Traffic Light	BC	2002-04	n/a	1.0	Engineering analysis based on on-site M&V and metering study
C&I Small Business CFL	BC	2004	n/a	1.6	Engineering analysis based on load profile and hours-of-use
C&I Custom Lighting	RI	2011	0.5	1.2	Engineering analysis based on metering and on-site M&V in compliance with ISO-NE FCM requirement
C&I Custom Lighting	RI	2008	0.7	1.4	Engineering analysis based on on-site M&V including metering, survey and sampling
C&I Custom HVAC	RI	2008-09	3.9	0.4	Engineering and energy model simulation, and on-site M&V in compliance with ISO-NE FCM requirement
C&I Custom Process and Compressed Air	RI	2010	0.8	1.0	Site-specific engineering and calibration analysis, and on-site M&V in compliance with ISO-NE FCM requirement
Residential Appliance Rebate	ME	2013			

Portfolios/Programmes	Region	Year	PER$_S$	PER$_W$	Key Notes on Evaluation
Heat Pump Water Heater			0.7	n/a	Engineering analysis based on metering and monitoring, and sampled on-site M&V in compliance with ISO-NE FCM requirement
Refrigerator			1.0	n/a	
Clothes Washer			1.3	n/a	
Dehumidifier			2.0	n/a	
Others			1.5	n/a	
Residential Lighting	ME	2011	0.8	2.2	Engineering analysis based on metering and monitoring, and sampled on-site M&V in compliance with ISO-NE FCM requirement
Residential Low Income Appliance Replacement	ME	2006			Engineering analysis with metering study for determining energy savings and coincidence factors
Lighting			1.4	3.2	
Refrigerator			1.2	1.2	
Residential Home Energy Solutions	CT	2008			Engineering and energy model simulation, and sampled on-site M&V in compliance with ISO-NE FCM requirement
Lighting			0.8	1.9	
Water Heating			0.8	0.9	
Building Envelope			6.4	1.0	
Residential WRAP and Helps Programmes	CT	2007-08			Engineering and energy model simulation, and sampled on-site M&V with metering and monitoring
Lighting			0.9	2.1	
Refrigerator			1.6	0.9	
Cooling			20.0	n/a	
Building Envelope			0.9	4.1	
Water Heating			1.0	1.3	
Residential Central AC	CT	2011-2012	10.7	n/a	Regression modelling and sampled on-site M&V in compliance with ISO-NE FCM requirement. Peak demand impacts estimated as occurring during ISO-NE FCM Seasonal Peak Periods
Residential Ground Sourced Heat Pump	CT	2012	1.2	2.1	Energy model simulation and sampled on-site M&V with metering. Peak demand savings are calculated by averaging savings over hottest or coldest 10 hours in summer or winter respectively
C&I Small Business Energy Advantage - Lighting	CT	2011	1.6	n/a	Engineering and billing analysis, and sampled on-site M&V with metering and monitoring. Peak demand impacts estimated as occurring during ISO-NE FCM Seasonal Peak Periods
C&I Small Business Energy Advantage	CT	2007			Engineering analysis and sampled on-site M&V with metering and monitoring.
Lighting			2.2	1.2	
Refrigeration Controls			0.1	0.1	
Compressed Air			12.6	12.6	
C&I Energy Opportunities - Lighting	CT	2008, 2011	1.5	1.2	Billing regression analysis and sampled on-site M&V in compliance with ISO-NE FCM requirement. Peak demand impacts estimated as occurring during ISO-NE FCM Seasonal Peak Periods
C&I Energy Conscious Blueprint	CT	2009			Engineering analysis and energy model simulation, and sampled on-site M&V including metering and monitoring
Lighting			1.3	1.2	
Space Cooling			2.5	0.6	
HVAC motors			0.7	0.9	
Process			1.8	0.9	
Residential Consumer Energy Efficiency	ON	2011-13			Engineering analysis based on prescribed assumptions and metering analysis
Lighting			0.4	n/a	
Appliance			1.3	n/a	
Furnace with ECM			4.4	n/a	
Space cooling			9.1	n/a	
Dehumidifier			4.1	n/a	
Water Heating			0.9	n/a	
Residential New Construction Initiatives	ON	2013			Engineering analysis based on prescribed assumptions and document analysis
Furnace with ECM			2.5	n/a	
Lighting			0.6	n/a	
C&I Small Business Lighting	ON	2011-12	2.9	n/a	Engineering analysis based on on-site measurement (Option A of IPMVP) for selected sample
C&I High Performance New Construction	ON	2013			Engineering analysis based on prescribed assumptions and document analysis
Lighting			1.4	n/a	
Appliance			1.1	n/a	
Space cooling			5.0	n/a	

Portfolios/Programmes	Region	Year	PER_S	PER_W	Key Notes on Evaluation
Agribusiness ventilation			3.0	n/a	
C&I Retrofit Initiative - Lighting	ON	2011-13	1.6	1.1	Engineering analysis based on document review and sampled site-specific M&V with metering and monitoring in compliance with OPA EM&V Protocols and IPMVP

5 | Paper 2: Incentivising electricity use reduction: empirical evidence of benefits and limitations of a savings-based approach for incentivising electric energy efficiency in North America and Europe

After Paper 1 examines H1 and finds that peak savings and energy savings are not necessarily well aligned, Paper 2 turns to H2 and focuses on whether another key element of design, i.e. the 'savings-based approach' for providing financial incentives, would be effective in driving electric EE investment. As can be seen later in the paper, it finds that savings-based approach is valuable but its use is limited to non-residential sectors, with its application in residential sector largely unexplored – this topic is to be examined in Paper 3.

5.1. Abstract

Financial incentives are often given to customers to encourage investment in electric energy efficiency. Different from traditional prescriptive schemes that give incentives based on type and units of equipment or capital investment, a new savings-based approach rewards projects based on verifiable electricity savings. To contribute to the theoretical literature on the role of a savings-based approach, this study empirically identifies and examines savings-based schemes in North America and Europe to understand their benefit and limitation for promoting electric efficiency. It finds that a savings-based approach is flexible to fit with diverse project and customer needs and can make valuable contributions in acquiring efficiency resources. However, this benefit is limited to non-residential sectors, and mostly customised projects or those above a certain size. It highlights the value of savings-based incentive schemes in complementing rather than replacing prescriptive schemes. While the savings-based schemes show the potential for incentivising non-lighting measures, they seem less successful in promoting comprehensive projects. This suggests the need for additional policy provisions to address barriers in project finances, and motivations, skills and resources for undertaking comprehensive retrofits. Development of the energy service

industry should also be a policy imperative well aligned with the implementation of savings-based incentive schemes.

Key Words: energy efficiency; electric; incentive; savings-based

5.2. Introduction

Electric energy efficiency (EE) is key to a policy landscape defined by climate change, system reliability and economic efficiency (Gilleo et al., 2015b; IEA, 2015; IPCC, 2014). It is also considered vital for industrial competitiveness and productivity (HM Government, 2017). It is defined as a variety of measures (e.g. lower energy ratings, insulation) to reduce electricity use at customers' end to provide the 'same or greater' service[52] (Furrey and Black, 2009). There is a rich literature on the market barriers leading to a socially sub-optimal level of investment in electric EE measures, or 'efficiency gap' (e.g. lack of capital, split incentive, hidden costs) (e.g. Eyre, 1997; Golove and Eto, 1996; Sorrell et al., 2000). To address these barriers, a multitude of policies (e.g. utility EE obligations, low-cost loan, product standards and energy feedback) are introduced (e.g. Darby et al., 2013; Eyre et al., 2015; Rosenow et al., 2016a).

Incentive schemes[53] are often available for customers to address the financial barriers in EE investment (e.g. upfront cost, payback) (Brown, 2015). They can be offered by utilities, government or market regulator (Eyre et al., 2015; Rosenow, 2012). This paper focuses on schemes *directly facing customers* in participation and access of financial incentives. To give financial incentives, these schemes employ two broad approaches. One is *prescriptive* – it requires customers to install *specific* EE measures in return for pre-defined incentives based on type and unit of measures, or size of investment (e.g. discount or grant) (Bertoldi et al., 2013; de la Rue du Can et al., 2014; NAPEE, 2010). An alternative is *savings-based* in that customers receive

---

[52] This is to be distinguished from other related concepts including: 1) efficiency in generation and transmission, or the entire electrical system; 2) energy conservation that implies lower demand of energy services; and 3) fuel switching that substitutes electricity use with other fuels.

[53] The term 'scheme' is used to make the distinction with broad policy programme like utility energy efficiency obligation.

incentives based on project savings (e.g. kWh or kW) and may face penalty in the event of shortfall in the committed savings. Consistent with Cowart and Neme (2013), this paper defines savings as electricity use reduction that can be *metered or estimated* with well-established factors, depending on the nature of project and EE measures. In the literature, savings-based incentive (SBI) scheme like 'feed-in tariff' for electricity demand reduction is proposed as a new approach for supporting ambitious carbon mitigation goals (Bertoldi et al., 2013; Eyre, 2013a). SBI schemes may provide pre-defined incentives as in many 'standard offer' schemes in the U.S., or use competitive auctions to set incentives. For example, the Electricity Demand Reduction (EDR) Pilot in the UK that uses 'technology-neutral' auctions to give incentives based on project peak savings (DECC, 2014a).

In contrast to a prescriptive approach, savings-based incentive (SBI) schemes have two unique features. First, a SBI scheme focuses more on how much savings a project can deliver rather than what EE measures are installed. If eligibility requirements are met, customers tend to have a higher flexibility in project design. Second, under a SBI scheme, it is customers that need to prove savings with appropriate measurement and verification (M&V) methods. Essentially, this shifts the burden of M&V and risk of energy savings from the programme administrator as in a prescriptive scheme (i.e. customers get incentives regardless of how much savings supported measures eventually realise) to customers sponsoring EE projects. It should be noted that SBI is distinct from 'white certificate' schemes where utilities receive incentives by trading energy savings (Bertoldi et al., 2010). The former is principally *a value proposition offered directly to customers*, while the latter amounts to a regulatory framework defining how obliged utilities can achieve their saving targets and is not directly facing customers (OECD/IPEEC, 2016).

While the importance and high-level 'best practices' (e.g. funding source, interaction with standards and product labelling) of incentive schemes are well discussed in literature (e.g. Geller and Attali, 2005; Hilke and Ryan, 2012), further analysis is still needed on how the diverse design and implementation of incentive schemes (e.g. approach of giving incentive and its structure) influence the effectiveness and cost-efficiency of energy saving (de la Rue du Can et al., 2014). Compared with a prescriptive approach, SBI is presumed to have several benefits. In the consultation for designing the EDR, the UK government cited three expected benefits of a savings-based approach (DECC, 2012, 2013a). First, its flexibility would allow EE opportunities, distributed across sectors and technologies, to be effectively captured. Second, it could foster innovation in project design and adapt to market changes. Third, it would drive deep savings in EE projects. Moreover, the shift of the M&V burden and savings risk to project sponsors in a SBI scheme would lower reliance on utilities and support new market entrants, thus creating a market-based delivery model and supporting market innovation (e.g. Eyre, 2013a; Neme and Cowart, 2013).

Nevertheless, the literature is limited on how these presumed benefits would materialise in practice, in relation to scheme designs. While some studies have looked at SBI schemes (e.g. Amann and Mendelsohn, 2005; Kwatra and Essig, 2014), the focus is on theoretical considerations of the scheme design like eligibility, determination of incentives, M&V and funding source (e.g. Bertoldi and Rezessy, 2007; Bertoldi et al., 2013; Bertoldi et al., 2009; Cowart and Neme, 2013; Eyre, 2013a), or high-level implementation principles, without explicitly examining these benefits. Better empirical knowledge can help build stakeholder confidence in the benefits of savings-based schemes and contribute to the debate about their value or limitation in supporting more ambitious energy-saving policy targets.

This study aims to fill the gap by examining *what* the benefits are of a savings-based approach and *for whom*, and *how* these benefits would realise in practice. It does so by reviewing identified SBI schemes in North America and Europe, and by analysing the logic behind key design features of SBI schemes and outcomes in relation to project characteristics, customer participation and activities of third parties like energy service providers (ESCos). It is not a comprehensive discussion of all individual schemes – it focuses on whether the presumed benefits of SBI can be examined empirically across schemes. After discussing the methodology for identifying SBI schemes (Section 5.3), it synthesises how SBI schemes are designed in practice, and the link with policy objectives (Section 5.4). Using evaluation results, Section 5.5 analyses the outcomes of savings-based schemes and discusses their benefit and limitation in promoting electric efficiency. Conclusion and policy implications are in Section 5.6.

5.3. Methodology

To start with, the analysis identifies incentive schemes that *directly* face customers and use a savings-based approach to give financial incentives for encouraging electric EE. Customers should be able to directly apply with EE projects, while third-parties like ESCos may participate on behalf of customers. For example, the Demand-Side Efficiency Promotion Plan (PPEC) in Portugal is excluded because it relies on utilities and intermediaries (e.g. municipal/business associations) to dispense incentives, while individual customers may not directly bid to obtain funding (Sousa, 2017; Sousa et al., 2015). SBI schemes can be offered by utilities, the government or market regulator. The literature (e.g. Sinton and Wit, 2014), Database of State Incentives for Renewables and Efficiency in the U.S. (DSIRE, 2016), and websites of utilities and market regulators in North America and Europe are consulted. This paper focuses on schemes with adequate documentation in English – which is limited by what is publically available – and has found 124 schemes. Electric system operators like ISO New England (ISO-NE) and PJM allow EE to bid in forward capacity markets that reward based on peak savings. These schemes are excluded as most of the participation is not from customers directly but from obliged utilities offering their efficiency portfolios in the capacity auctions (Liu, 2017). The EDR Pilot in the UK is a trial to integrate EE in the Great British (GB) Capacity Market. The EDR is included in the analysis due to its attempt to solicit projects directly from customers (DECC, 2014a, 2015a).

In analysing these SBI schemes, there are two dimensions. First, scheme documents and websites are reviewed to synthesise key aspects in design: target customers and end-use categories, incentive structure and technical assistance. The logic as implied in design features like causal links and expected mechanisms for achieving specific policy objectives (e.g. CPUC, 2006; Harmelink et al., 2008) is identified for understanding the link with design features. This follows the general framework of theory-based evaluation of EE policy whereby the policy logic is drawn as to the various steps in how the policy is supposed to work and the relationship of key actors, for understanding the success in design and implementation (AID-EE, 2006; Harmelink et al., 2008).

Second, for analysing the scheme outcomes, impact and process evaluation reports[54] are obtained from websites of administrators or regulators. The analysis focuses on a few SBI schemes that publish these reports. For the U.S. and Canada, 40 impact evaluation and 35 process evaluation reports[55] are obtained and reviewed for 18 SBI schemes in 11 jurisdictions. For three schemes in Europe, reports on the scheme outcome and mechanisms are also analysed. Net *ex post* energy savings[56] (e.g. overall and by end-uses and customers), project number and types, and programme costs are collected from impact evaluation. If a given SBI scheme is part of an electric efficiency portfolio, energy savings and costs of that portfolio are collected, to benchmark cost-effectiveness. Process evaluation complements impact evaluation in elucidating scheme processes and how outcomes relate to the scheme design (SEEAction, 2012; Wade and Eyre, 2015a). They are synthesised to elucidate the drivers and barriers for customer participation.

5.4. Design of SBI schemes

Key design aspects of SBI schemes are summarised in Fig. 5-1. Most of them (97%) use administratively set incentives for energy- and/or peak-savings. Only 6 schemes use competitive auctions to determine and allocate incentives. The experience of SBI schemes is stronger in the

---

[54] Impact and process evaluation reports are not available for all the identified schemes. Even for those with impact evaluation, only a few are evaluated for programme logic and implementation (i.e. process evaluation). Moreover, impact evaluations may not be consistently reported, with some not reporting all the aspects this study is interested in (e.g. costs and breakdown by end-uses and customers).

[55] In many cases, the findings of impact and process evaluations are reported in a combined document

[56] Net savings refer to impacts directly attributed to the programme (i.e. discounting free-rider effects from gross savings). *Ex post* means evaluation after the programme implementation, while ex ante means assumed impacts before programme implementation. *Ex ante* or gross savings are used where net ex post savings are unavailable.

U.S. (113 schemes), while there are eight schemes in Canada and one auction-based SBI each for the UK, Switzerland and Germany. Regardless of the diverse designs, which reflect specific regulatory and market conditions, this section focuses on key scheme designs and how they relate to policy objectives. This paper distinguishes SBI schemes using pre-defined incentives (i.e. 'non-bidding') and competitive auction to allocate incentives (i.e. 'bidding').

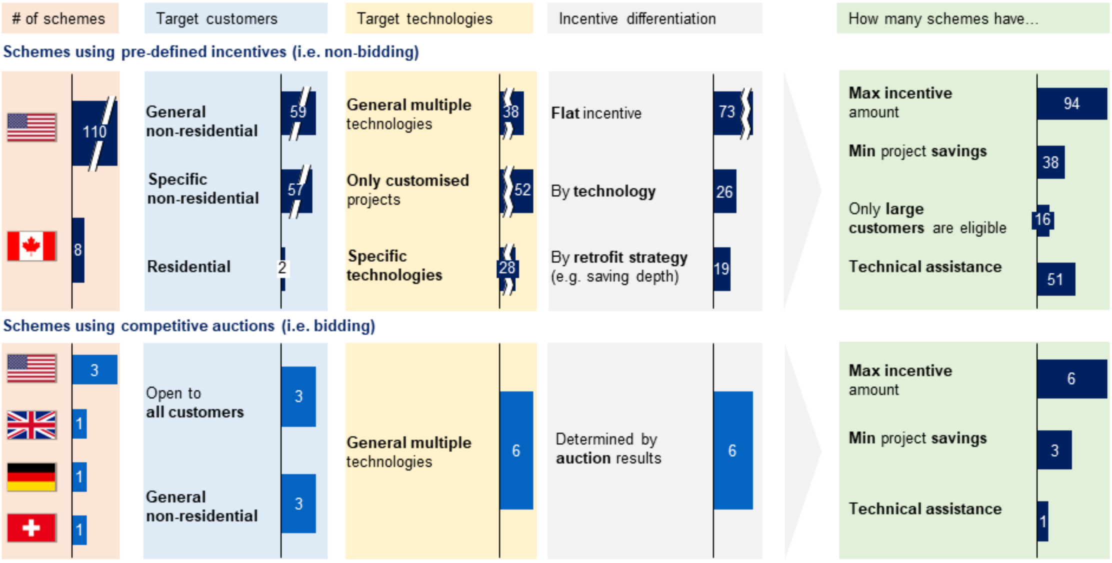


Fig. 5-1. Key characteristics of identified savings-based incentive schemes

5.4.1. Target sectors and technologies

The pattern by which SBI schemes target customers and end-uses for electric efficiency can be characterised in three aspects. First, most of the non-bidding SBI schemes (98%) are offered to non-residential customers only, splitting almost evenly between targeting non-residential sector generally (e.g. commercial, industrial and public) and focusing on specific customers in these sectors (e.g. type and size of customers, process types). For the latter, limiting the eligibility to certain customers appears to reflect the difference in needs and capabilities of customers (e.g. equipment replacement cycles, internal budget, project planning and management) that merit tailored programme designs, rather than the lack of electric efficiency potential in customers not covered. For example, parallel SBI schemes for distinct customers are often offered in the same jurisdiction. In New York, the Industrial and Process Efficiency Programme focuses on process efficiency in manufacturing industries and data centres, complementing other schemes (e.g. Existing Facilities Programme) with limited success in tapping into the efficiency opportunities in industrial processes (GDS Associates and Navigant, 2012). The MidAmerican Energy Efficiency Bid is designed for large industrial customers to accommodate their specific technical and programme needs (Leuthauser et al., 2005). Moreover, only two residential schemes in California and Idaho (e.g. whole house efficiency improvement and building insulation) use the non-bidding savings-based approach.

For bidding SBI, three schemes in the U.S. are for large non-residential customers or specific EE opportunities (e.g. innovative technology or design assistance). In Europe, all of the three schemes are open to all sectors. There are two points. First, while the EDR Pilot in the UK is in principle open to all customers, its auctions only managed to procure resources from non-residential sectors (Section 5.5.1). Second, the other schemes in Germany and Switzerland are introduced *in lieu* of utility EE obligation. Both offer *'tranched'* auctions for applicants (e.g. large customers or aggregators) or types of measures (Lerch, 2017; OECD/IPEEC, 2016; Radgen et al., 2016). The ProKilowatt in Switzerland conducts separate auctions for large customers for their projects ('project') and smaller customers (e.g. small companies and households) in a bundled programme implemented by aggregators ('programme'). For the 'STEP up!' scheme in Germany, the distinction is similarly made between 'individual projects' by non-residential customers, and 'collection projects' aggregating over smaller customers – in its first auction in 2016, 'collection projects' focused on white appliances for households (Lerch, 2017). So, consistent with non-bidding SBI, bidding SBI *effectively* focuses on non-residential customers in terms of direct customer participation. In the cases of Switzerland and Germany, residential EE is procured with customer propositions designed by aggregators or intermediaries, not the SBI scheme.

Second, in many cases, the eligibility is limited to projects above a certain size. Of all the identified schemes, 32% set minimum thresholds for projects' energy- or peak-savings, space area affected or amount of incentives from a given scheme. Moreover, another 13% of the SBI schemes target customers with higher energy use or peak demand (e.g. industrial customers), projects of whom tend to be larger in scope and savings for the same percentage of reduction.

Third, regarding the types of measures targeted, 42% of the schemes are designed specifically for customised projects not accommodated in schemes using prescriptive incentives for more standard or simpler measures (Leuthauser et al., 2005). Besides, 23% of them target specific technologies (e.g. HVAC and lighting), with another 9% for new construction projects. As it suggests, the savings-based approach is most typically to complement schemes with a prescriptive incentive structure in capturing customised measures, rather than replacing the latter for promoting electric efficiency measures.

The tendency of SBI schemes to be used for non-residential customers – and in many cases for customised projects or those above a certain size – can be explained by two reasons associated with the objective of cost-effective EE procurement. First, prescriptive schemes, while effective in promoting more standard efficiency equipment, are less so in capturing the potential of customised EE measures (e.g. industrial processes) that are common in non-residential sectors (York et al., 2013). Heterogeneous electricity usage patterns and actors in non-residential buildings (e.g. Axon et al., 2012; Janda, 2014) suggest the value of a flexible savings-based approach in capturing customised opportunities, demonstrating savings and addressing unique needs of customers.

Second, with finite resources (e.g. budget and staffing), efficient scheme operation is a priority. As savings-based projects entail technical review and dedicated participation support, it requires time and expertise of scheme administrators (e.g. DECC, 2014a). To reduce the administrative burden, schemes tend to set a threshold for a minimum project size or target large customers and efficiency projects with a high savings potential. For the Ontario Business Retrofit Incentive, utilities mentioned focusing on key account customers, citing the low saving potential of small customers as the reason (Nexant, 2013). As seen in the EDR Pilot, minimum savings may be reduced to support small projects but only on a balanced weighing of additional administrative costs (BEIS, 2017). For households, given its lower per-customer saving potential, it would be difficult and potentially costly to accept applications directly from households. While the Standard Offer in Texas targets residential efficiency resources, it relies on a network of third-party energy service providers to aggregate from households, thus reducing scheme's administrative burdens.

5.4.2. Financial incentives

Three aspects of incentive structure are noteworthy. First, while bidding schemes tend to favour low-cost projects – although 'tranched auctions' may be used to support specific technology, sector or project (e.g. Lerch, 2017; Radgen et al., 2016) – non-bidding SBI demonstrate some flexibility in structuring the incentives for certain policy objectives. For 37% of the non-bidding schemes, incentives are differentiated among retrofit strategies (e.g. focusing on specific systems vs. whole building), end-use categories or depth of savings. In principle, this strengthens the financial support for projects with a comprehensive design (i.e. affecting multiple systems) and deep saving potential, or targeting costlier efficiency opportunities (e.g. non-lighting, or certain customers). For example, in Ontario, the Business Retrofit Incentive and the engineered component of High Performance New Construction set incentives for non-lighting measures at twice that for lighting. The Pay-for-Performance of New Hampshire rewards projects saving more than 15% of energy costs at a level up to twice that for those saving less than 15%.

Second, another 13% of the identified non-bidding schemes encourage comprehensive projects with minimum savings, minimum number of end-use measures affected, or maximum savings or incentives for specific end-uses. In fact, the PacifiCorp Energy FinAnswer requires energy savings from lighting to be below 50% of project savings, while the Pay-for-Performance of New Hampshire asks projects achieving less than 15% savings to install at least two measure categories.

As it costs to recruit customers, comprehensive projects have the practical benefit of increasing savings per customer, by scaling up the prospected project or capturing as many efficiency opportunities as possible, thus supporting ambitious saving targets (York et al., 2013). The New Jersey Pay-for-Performance takes a ‘comprehensive, whole-building’ approach towards efficiency projects, requiring them to achieve at least 15% energy savings. However, being comprehensive does not necessarily mean that *all* energy opportunities are exhausted in one go – customers can undertake upgrades in phases or include the opportunities viable within the practical constraints.

Third, most of the SBI schemes (80%) usually cap the total reward for a project or applicant. This has to do with the objective of encouraging participation of a wider customer base and high impacts attributable to the scheme (Rohde et al., 2015). On the contribution of incentives to project costs, most of the schemes require the share to be below 50-70%, while the cap in the Pay-for-Performance of New Jersey is 25%. This means that customers would need to leverage other sources of funding. Moreover, a minimum payback is another design option to discourage free-ridership so that supported projects are those that would not be possible without incentives (i.e. ‘additionality’ of saving). For instance, the NYSERDA Commercial New Construction and PacifiCorp Energy FinAnswer limit eligibility to projects of paybacks over one year. There is a tension, however, between additionality and procurement of cost-effective measures. As discussed below (Section 5.5.1), the EDR Pilot has limited success in acquiring electric efficiency from non-residential customers. Its two-year minimum project payback has contributed to the hindrance of participation.

5.4.3. Technical assistance

Many of the non-bidding schemes (43%) also provide technical assistance in terms of energy audit, engineering analysis or project design. There are three forms of support: 1) in-house support for preliminary energy analysis, 2) funding for detailed engineering analysis and 3) scheme implementation using approved energy service providers to identify efficiency opportunities and design projects (e.g. Pay-for-Performance in New Jersey and New Hampshire). For NYSERDA Industrial and Process Efficiency Programme, although no technical assistance is included, NYSERDA shares the cost of site-specific analysis for potential participants through the Flexible Technical Assistance.

However, bidding schemes tend not to provide technical assistance and participants are expected to acquire technical expertise, either in-house or externally. This may be explained by two reasons. First, bidding schemes allocate budget competitively based on bid price and project savings. As the energy analyse is funded with a lump sum, it is inconsistent with competitive bidding and a separate funding is needed. Second, for the MidAmerican Energy Efficiency Auction, it is specifically set up to *leverage* the ‘specialty technical expertise’ of large manufacturing customers (Leuthauser et al., 2005).

5.4.4. Project evaluation and customer engagement

Projects approved, or successful in auctions, in the SBI schemes are subject to project-based M&V (DECC, 2014a; Kwatra and Essig, 2014). International Performance Measurement and Verification Protocol[57] (IPMVP) is typically followed to establish M&V requirement (e.g. DECC, 2014b; Navigant and EMI, 2015a, b, c). It is possible to use simple engineering analysis for measures whose savings can be estimated using well-established factors (e.g. lighting, motors), coupled with in-field measurement of operation parameters (DECC, 2014b). For complex projects

---

[57] Developed by the Efficiency Valuation Organisation (EVO)

or those of significant savings, rigorous M&V methods are needed that involve metering, modelling and site visit.

Dedicated marketing and engagement activities are also important. For the EDR Pilot, workshops were held to familiarise customers with participation rules. Similar outreach is widely used in other SBI schemes and a number of ‘good practices’ are suggested in attracting customers and marketing SBI schemes (Kwatra and Essig, 2014). These include using benchmarks to show the efficiency potential, following up on energy assessments or remote audits, showcasing the value of comprehensive project designs, and reconnecting with customers previously participating in other EE schemes. For the SBI schemes in North America, it is common to rely on trade allies (e.g. ESCos and contractors), and utilities’ relationship with key customers, to promote project opportunities (discussed further in Section 5.5.5).

5.5. Empirical outcomes of SBI schemes

5.5.1. Contribution to the procurement of electric efficiency resources

The savings-based approach has played a key role in procuring electric efficiency, at least in non-residential sectors (Fig. 5-2). For most of the 10 portfolios reviewed, SBI schemes contribute 30-66% to the cumulative annual energy savings of all non-residential schemes. In those portfolios, as SBI schemes are often for customised projects, this indicates the scale of such efficiency opportunities and the benefit of a savings-based approach in capturing them. Texas (2006-08) is an exception in that C&I Standard Offer Programme accounts for 88% of cumulative annual energy savings of non-residential schemes. It is because the savings-based approach is widely used to procure electric efficiency from non-residential customers.

The contribution of non-residential SBI schemes to the overall efficiency portfolio, however, varies widely across jurisdictions, ranging from 4% in New Jersey (2010-14) to 49% in Ontario (2013-14). It depends chiefly on the position of non-residential schemes in entire efficiency portfolio, reflecting the heterogeneous focus and strategy of individual portfolios in developing electric efficiency resources. In Texas (2006-08), the strong position of Standard Offer Programme in the non-residential portfolio plays an even bigger role in underpinning its large share of the portfolio savings.

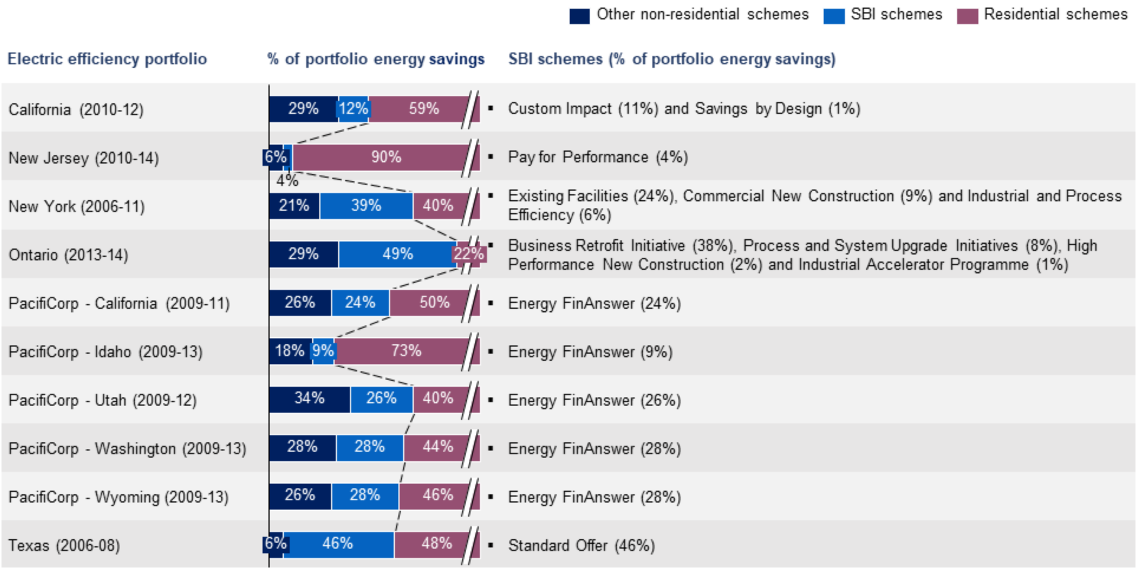


Fig. 5-2. Contribution of savings-based incentive schemes to cumulative energy savings of efficiency portfolios

The EDR Pilot in the UK is the only scheme that pays EE projects based exclusively on coincident peak savings. It is also the only government scheme for promoting electric EE because supplier obligation has recently changed to focus on insulation that mostly affects gas use and with a considerably lower policy ambition (Rosenow and Eyre, 2015). Two EDR auctions have taken place. There are two points (DECC, 2015d, 2016c). First, while the EDR is in principle open to all sectors, the procured savings mostly come from non-residential customers. Of these two auctions, the cleared bids from C&I customers account for almost 90% of allocated budget – the remaining 10% goes to local authorities. Even if all the 10% is for projects on social housing properties maintained by local authorities, the share is small given that residential sector is estimated to contribute ~40-45% of winter peak in the GB system (Brattle Group and Sustainability First, 2012; Darby and McKenna, 2012). Second, the EDR has limited success in acquiring electric efficiency, with only 13% and 80% of budget was allocated respectively in the two auctions. According to the interim evaluation (BEIS, 2017a), it is largely due to unfavourable weighing of low incentive level based on peak savings (i.e. 10-15% of project costs) and barriers for participation like rigid rules (e.g. two-year minimum payback, minimum peak savings) and deadlines, complex processes and M&V data needs, limited internal resources and risks of not clearing competitive auctions.

5.5.2. Cost-effectiveness

In terms of cost in saving energy, SBI schemes can be almost similar with other non-residential EE schemes. The levelised costs of energy saving, i.e. programme costs[58] divided over cumulative lifetime energy savings, for 5 SBI schemes[59] are calculated, and are compared with the average levelised costs of their respective non-residential efficiency portfolios (Fig. 5-3). The levelised costs of energy saving differ across SBI schemes, from ¢2.2/kWh to ¢3.3/kWh. However, they are almost comparable to the average cost of energy saving of non-residential portfolio.

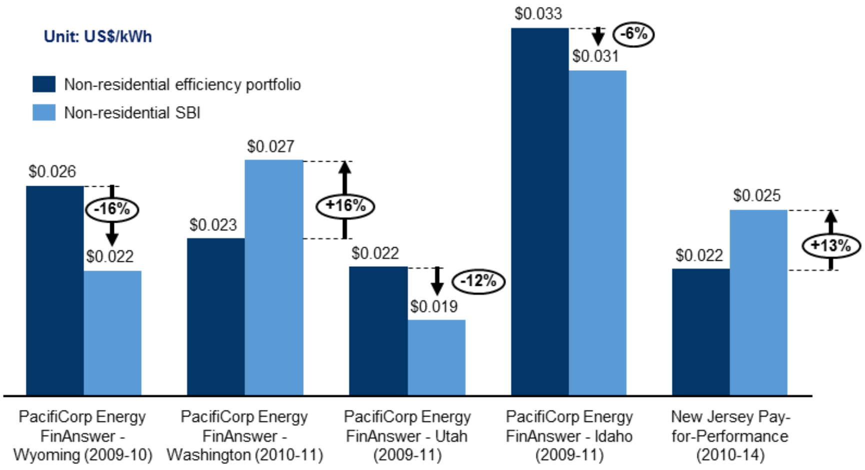


Fig. 5-3. Levelised cost of energy savings in savings-based incentive schemes (discounting rate 0%)

---

[58] Costs of running schemes to utilities. In other words, they are not societal costs and thus not directly comparable to generation.

[59] For PacifiCorp Energy FinAnswer schemes, net lifetime energy savings are used for calculating the levelised cost of energy saving. For New Jersey Pay-for-Performance programme, gross lifetime savings are used since net savings are not reported.

Moreover, there is some evidence suggesting that non-residential SBI schemes can help leverage private funding for electric efficiency projects. For example, the financial incentives of New Hampshire Pay-for-Performance and PacifiCorp Energy FinAnswer in 5 states has contributed 23-30% of the costs of efficiency projects, which is lower than the incentive cap of 50% project costs (Fig. 5-4). In other words, these SBI schemes have managed to encourage customers to tap into other funding sources (e.g. own funding), with a 'leverage' ratio of 2.3-3.4[60].

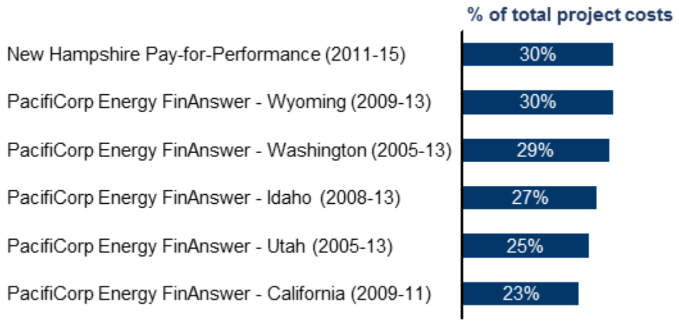


Fig. 5-4. Share of savings-based incentives in total programme and project costs

5.5.3. Promoting energy efficiency in multiple end-use categories

Energy efficiency opportunities can be found in a variety of end-use categories. Lighting, especially in households, has been the major source of cost-effective energy savings in many efficiency portfolios (e.g. Liu, 2015; York et al., 2013). While new technologies like LED imply further efficiency potential in lighting, ambitious energy-saving targets mean that efficiency schemes should also focus on non-lighting measures (Grueneich, 2015). This has to do with not just the growing stringency of efficiency standards and codes (e.g. for lighting) that reduce the savings schemes can claim, but also the huge untapped potential in areas like heat pumps, operation of commercial building systems and optimisation of industrial processes (York et al., 2013).

---

[60] High leverage of other funding apart from programme incentives does not suggest cost-effectiveness of installed measures.

On a project level, this emerging agenda requires a programme design that can incentivise a holistic or 'comprehensive' approach for efficiency improvement to cover multiple end-use categories, which is conducive to deep savings in buildings and industrial processes. As demonstrated by savings-based projects in NYSERDA Existing Facilities over 2008-11, the average per-project energy savings of non-lighting measures are at least 55% higher than that of lighting (Navigant, 2012).

a) Non-lighting efficiency measures

Evidence shows that SBI schemes can be designed to promote electric efficiency investment in non-lighting end-uses (Fig. 5-5). Of the 11 non-bidding SBI schemes that report impacts by end-use categories (e.g. heating and cooling, motors, whole-house approach), non-lighting measures make up at least 39% of cumulative annual energy savings of scheme. Their share is over 80% in NYSERDA Industrial and Process Efficiency (2010-12), Ontario High Performance New Construction (2011-14) and PacifiCorp Energy FinAnswer in Idaho (2008-13), Utah (2005-13), Washington (2005-13) and Wyoming (2011-13). The bidding programme, MidAmerican Energy Efficiency Bid, seemed successful in encouraging custom projects for specific industrial processes, with less than 3% of projects for 2014-17 targeting lighting uses (Mueller et al., 2007).

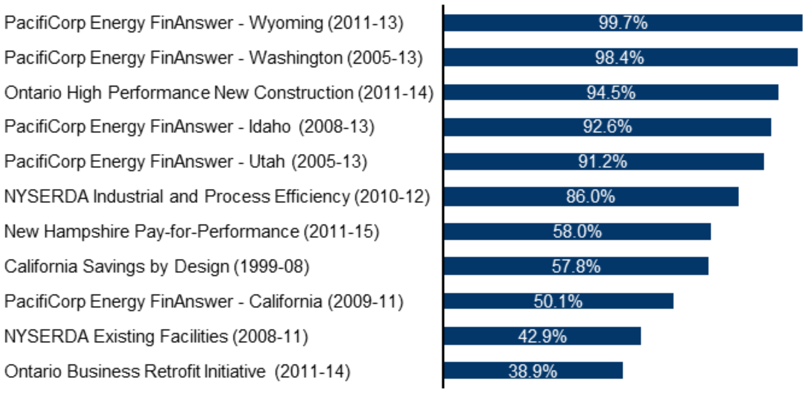


Fig. 5-5. Share of non-lighting measures in energy savings of savings-based incentive schemes

The success in acquiring non-lighting efficiency resources seems to be associated with the focus of schemes on certain non-lighting opportunities (e.g. industrial process) and sectors (e.g. large customers), for which non-lighting measures have greater saving potentials, or the predominance of comprehensive projects. Moreover, that more standard measures (e.g. lighting upgrades) are already covered by other prescriptive schemes (e.g. for MidAmerican Energy Efficiency Bid and PacifiCorp Energy FinAnswer) may also play a part.

For the EDR Pilot in the UK (2015-18), by contrast, 98.6% of the allocated budget goes to lighting projects. This can be explained by three reasons (BEIS, 2017a). First, lighting projects (e.g. LEDs) are the cheapest – as competitive auctions select projects of lowest bid price first, this effectively favours projects focusing on cheaper measures, especially those most likely to be used during the winter peak. Second, partly due to the tight timeframe for application, a lighting project is straightforward and can be easily adjusted to fit participation requirements (e.g. minimum peak savings). Third, savings of lighting can be 'deemed' with lower data input for M&V (e.g. no need of metering data) – this reduces the requirements on customers and the financial risk of under-delivery of peak savings. In fact, for the auction for 2016-18, 76% of the successful projects have opted for the 'deemed savings' approach using factors stipulated by the government.

b) Comprehensive efficiency projects

However, projects simultaneously affecting multiple end-use categories in an individual site are not common. In NYSERDA Existing Facilities (2008-11), only 4% of office buildings and hospitals completing savings-based projects included multiple end-use categories, while other projects in sectors like retail and public buildings focused on a single measure like lighting (Navigant, 2012). Consequently, on average, efficiency upgrades in a single site only include 1.1 measures. To strengthen the incentive for comprehensive projects, the Existing Facilities Programme later requires projects to affect at least two measure categories. For PacifiCorp Energy FinAnswer, the average number of EE measures affected in a single project is 1.3 in California

(2009-11) and 1.6 in Idaho (2009-13), while that for Washington (2009-13) and Wyoming (2011-13) is 2.0 and for Utah (2009-13) is 2.7.

This suggests barriers faced by customers regarding comprehensive efficiency projects. Although some of them are due to the internal requirements and priorities of customers, e.g. upgrade driven by replacement needs, longer lead-time for comprehensive projects and split incentive as noted by Kwatra and Essig (2014), others relate to the design elements of SBI schemes (see Kwatra and Essig (2014) and Quantum Consulting (2004) for more detailed discussions of scheme ‘good practices’).

- Upfront cost and long payback

The first barrier concerns the economics of investment. For the EDR Pilot, since the auction works to procure the lowest possible projects, there is little incentive for bidding in comprehensive projects, if doing so means a significant increase in project costs. In fact, of the small number of cleared projects (4 out of 59) that include non-lighting measures, reason for doing so is insufficient lighting savings to meet minimum peak savings, or coincidence that non-lighting projects are being progressed when the EDR auction is open (BEIS, 2017a). Moreover, since the payment, or at least a significant portion of it, would not be made until savings are verified, participants typically need to pay for the upfront costs. For Ontario Business Retrofit Incentive, a survey with contractors who reported trying to promote comprehensive retrofits to over 50% of their customers cited upfront costs and long project payback as the common reasons for not proceeding with the comprehensive project design (Nexant, 2013). Most of those successful in selling comprehensive projects mentioned that a strong case of investment return would be vital. As for factors influencing whether a specific measure is included, PacifiCorp Energy FinAnswer also finds that customers tend to cite financial incentive and project payback as key considerations (Navigant and EMI, 2013a, b, 2015a, b, c).

These underline the importance of not only the *availability* of financial incentives, but also *how they are structured*. There are two aspects. First, given the heterogeneity of costs in energy- or peak-saving of projects, a uniform incentive would inevitably favour cheaper and 'low-hanging' efficiency opportunities over those with a longer payback. As seen in Section 5.4.2, several ways can strengthen the financial incentive for comprehensive projects. One is a differentiated incentive structure based on the measures or project savings, giving an improved return of investment to costly measures. Another is a limit on the funding for any single measure category, or a minimum number of measures categories a project needs to affect. However, setting a differentiated incentive structure or 'comprehensiveness' requirement needs a robust gauge of retrofit market conditions and the capability of target customers. It is key to avoid undue burden on participation. For example, while the California CORE Calculated schemes limited the energy savings from lighting to up to 20% of project savings and the amount of incentives specific measures could obtain, the requirements were later lifted to streamline participation. Second, to address the high upfront costs of comprehensive projects, options may include dedicated financing solutions (e.g. low-interest loans) or a front-loaded schedule for making incentive payment in early stages of projects, while the latter needs to be balanced with the risks of project performance.

- Motivation or expertise for comprehensive improvement

Another barrier is the lack of motivation or expertise in identifying opportunities in multiple end-uses. On one hand, customers may not know the benefits of comprehensive efficiency upgrades, or cost-effective potentials are not fully assessed (Nexant, 2013). Indeed, it is why many SBI schemes offer technical assistance to customers, especially small ones, in assessing upgrade opportunities and associated saving potentials (e.g. Navigant and EMI, 2015b). The complicated M&V and project management may also have a 'chilling' effect on customers' motivation for comprehensive projects, particularly if they require higher technical expertise or time from the staff (Kwatra and Essig, 2014).

On the other, with the important role of third-party service providers (e.g. contractors and energy service companies) in influencing the project design (discussed in Section 5.5.5), it is essential that they have technical skills and experience for comprehensive engineering studies, equipment configuration and subcontracting arrangement (Kwatra and Essig, 2014). Considering this, they should be adequately motivated to acquire these skills and promote comprehensive projects. However, further policy support may be needed in this area. As revealed in the process evaluation of Ontario Business Retrofit Incentive, only 35% of the surveyed participating retrofit contractors indicated that they had experience 'planning projects with multiple equipment systems' (Nexant, 2013). Moreover, those with businesses focusing on specific measures are less likely to be involved in comprehensive projects. The market research for the NYSERDA Existing Facilities Programme surveyed 39 service providers that participated in the savings-based projects. It found that 64% of them had focused on lighting equipment but less than 18% of them had indicated focusing on other types such as heating, cooling and air-conditioning and motors (Navigant, 2012).

5.5.4. Project size and customer participation

There is evidence showing the flexibility of SBI schemes to fit with diverse customer needs and programme conditions, if eligibility requirements such as a minimum project size are met. As for annual energy savings, while the average project size is consistent with the tendency of SBI schemes to target projects above a certain size, it varies among schemes (Fig. 5-6). For most of the schemes, the average per-project saving is 76-600MWh/year, whereas for Process and Systems Upgrade Initiative (2013-14) and Industrial Accelerator Programme (2012-14) in Ontario, it is over 5GWh/year.

Two factors may contribute to this wide spread of average project size. First, on the project basis, efficiency upgrades in industrial premises tend to generate greater savings than commercial and public buildings (e.g. CADMUS, 2010a, b). Therefore, the contribution of industrial efficiency projects to the overall scheme impacts affects average per-project savings. In fact, the Process and Systems Upgrade Initiative and the Industrial Accelerator Programme in Ontario, and NYSERDA Industrial and Process Efficiency only target industrial sectors, whereas other schemes support a combination of commercial and industrial customers. Moreover, the larger share of savings from industrial projects in PacifiCorp Energy FinAnswer in Utah (2005-08) and Washington (2005-08) corresponds with their higher average per-project energy savings than the programme in Idaho (2008).

Second, even in the same sector, project size may differ considerably as well. In Business Retrofit Initiative of Ontario (2011-13), although most of projects were estimated to achieve savings of 15-30MWh/year, the size of other projects could be over 90MWh/year (Nexant, 2014). Such a diversity may reflect priorities or needs of efficiency projects, requirements of customers or specific potential for electric efficiency at customers' sites.

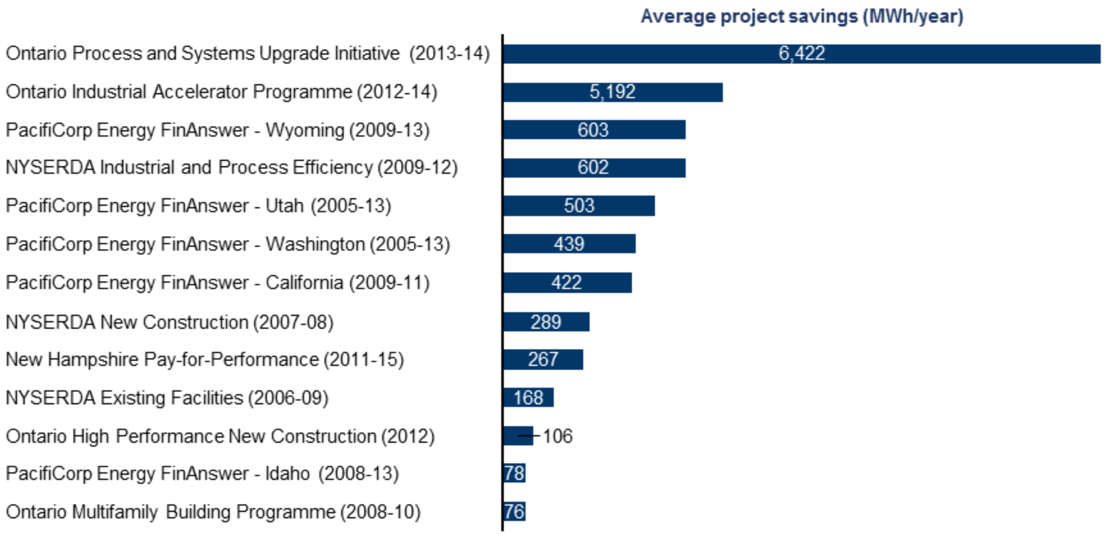


Fig. 5-6. Average per-project annual energy savings in savings-based incentive schemes

In terms of customers, the NYSERDA Existing Facilities, California Savings by Design (2002-08) and PacifiCorp Energy FinAnswer in Idaho (2008) achieved 61-95% of cumulative annual energy savings from projects of commercial and public customers (Fig. 5-7). For PacifiCorp Energy FinAnswer in Utah (2005-08) and Washington (2005-08), by contrast, industrial projects contributed 68-90% of cumulative annual energy savings.

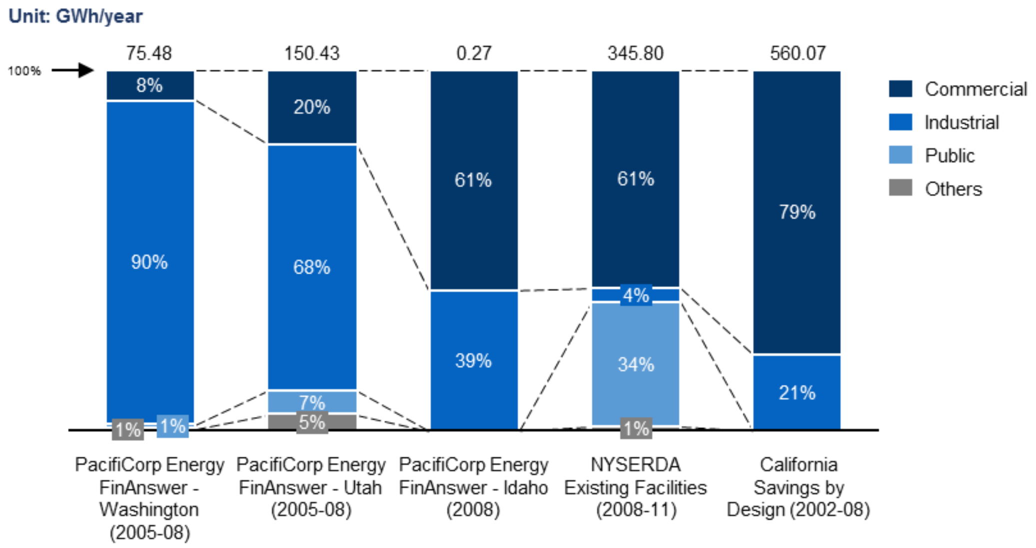


Fig. 5-7. Energy savings of savings-based incentive schemes by sector

It is not common for the evaluation reports to detail the characteristics of customers. However, there is some evidence that the savings-based approach can be applied to customers of different sizes. On one hand, schemes like the Ontario Process and System Upgrade Initiative target large industrial customers; on the other, examples such as PacifiCorp Energy FinAnswer show that it is feasible to work with smaller organisations. For example, in the process evaluation with participating organisations, over 68% of respondents to the survey in Utah (2005-11) and Washington (2005-11) are small- and medium-sized customers, respectively representing 13% and 43% of all the projects in these two states (CADMUS, 2010a, c; Navigant and EMI, 2012, 2013b). While this may not accurately reflect how important small- and medium-sized customers are to Energy FinAnswer, it highlights the possibility of savings-based approach in catering to the needs and characteristics of customers of varying sizes, thus capturing the efficiency opportunities.

However, this does not mean that customers face the same level of difficulty in taking part in these SBI schemes. For customers, apart from financial incentives that bear on the economic case of upgrades, another key area is the availability of internal resources. Implementing savings-based projects, arguably, requires high-level engagement and efforts from customers, which may be even higher in bidding SBI schemes given the auction processes and risk of not obtaining funding (Radgen et al., 2016). While it depends on project design and programme requirements, the process of project scoping, application and M&V may present challenges for small organisations without adequate internal resources or technical capability, especially if there is no prior experience with the savings-based approach. An evaluation for the EDR Pilot finds that availability of internal resources or external support (e.g. consultants) is one ‘necessary’ condition for successful participants, while it is cited as one barrier by those not applying (BEIS, 2017a). Although it is not impossible to source additional resources to support application, in the case of competitive auction, this needs to be assessed in balance with the risk of not clearing the auction. As seen in PacifiCorp Energy FinAnswer in Wyoming, the largest barrier for participation is customers’ lack of staffing resources and internal support (Navigant and EMI, 2011). For the Ontario Business Retrofit Incentive, in a survey with organisations aware of the scheme but not eventually participating, 50% cited resource limitation – i.e. time, knowledge and capital – as the reason for not taking part, while 7% mentioned programme requirements (Rearch Into Action, 2011).

Given that, two areas would be important for reducing the barrier for small organisations. First, if eligibility requirements (e.g. minimum project size) are appropriately set to ensure efficient programme operation, the procedures may be streamlined for easing participation, on a balanced consideration of any risk of project quality and impacts. In some cases, this could mean separate programme offerings for customers of different sizes (e.g. Entergy Arkansas and Eleco in Louisiana). Second, aggregation of projects from smaller organisations may present another valuable option (Neme and Cowart, 2013). There are some indicators that this model of participation can be viable. For instance, as discussed above, the ProKilowatt in Switzerland designed a separate auction for aggregated projects that have contributed 79% of energy savings of the scheme over 2010-15 (Radgen et al., 2016). In the EDR auction for 2016-18 in the UK, aggregated electric efficiency projects managed to take up 66% of the allocated budget (DECC, 2016a). However, how viable or salient the aggregation model can be would depend on several market factors including the revenue potential in SBI schemes, electric efficiency potential of customers and transactional costs for procuring it, and capabilities of aggregators themselves.

5.5.5. Role of energy service providers

The energy efficiency market comprises of diverse organisations providing not only equipment or technologies for efficiency improvement projects, but also a range of services like energy audit and analysis, technical support, monitoring and energy performance contracting.

Supporting the development of energy service market is one objective in some schemes. It means not just an increased demand for energy services (e.g. equipment, project contracting, technical support), but also the improved capability of market to deliver high-quality projects to meet scheme requirement. For the Existing Facilities Programme, as well as other non-residential schemes of NYSERDA, it is a key objective to support developing ‘competitive markets for energy efficiency services’, by increasing the demand for efficiency upgrades and the capability of energy service firms to deliver ‘quality projects’ (Navigant, 2012). This ‘transformation’ implies skills and expertise in designing and implementing savings-based projects as well as M&V, commercial experience in promoting opportunities for savings-based retrofits, and innovation in project design. In a way, the process of learning for energy service providers is arguably similar to if new low-carbon technologies are introduced (Fawcett and Boardman, 2009; Killip, 2011, 2013).

Evidence from the SBI schemes demonstrates that energy service providers play an important role in supporting both customers and the scheme (Fig. 5-8). As for the nature of support, one contribution to customers is technical assistance in various steps of project development, although the extent depends on the capability and resources of customers. For Ontario Business Retrofit Initiative, nearly all the surveyed participants cited having used third parties with expertise (e.g. contractor) in completing their applications. In fact, 74% and 37% of the surveyed participants mentioned contractors and formal audit respectively as the source for identifying upgrade opportunities (Nexant, 2014). Furthermore, projects using contractors or formal audit tend to generate statistically significantly higher savings than those without. It does not necessarily prove the causal effect of contractors or formal audit on higher project savings, as seeking assistance from contractors or formal audit may already indicate greater interest of customers in savings. However, it does suggest the key role such third-party energy services can play in encouraging savings.

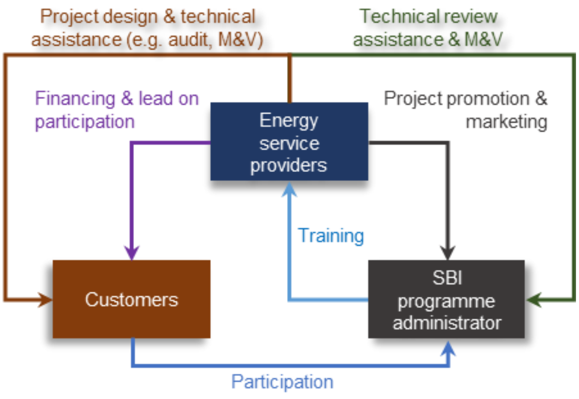


Fig. 5-8. Relationship of stakeholders in the savings-based incentive schemes

This role of assisting with customer projects may extend to be the lead applicant for savings-based funding. In NYSERDA Existing Facilities Programme (2008-11), of sectors contributing most savings, office and institutional organisations (i.e. health and education) designated ESCos as a lead on 54% and 47% of their projects respectively, while the share of projects other service providers sponsor is 16% and 30% respectively in these two sectors (Fig. 5-9). However, most of the projects in large retail stores were led by facility owners themselves, although ESCos and service providers are responsible for 29% of the projects. This is probably due to the project nature of installing similar equipment across relatively uniform retail premises, thus requiring lower support from external energy service providers (Navigant, 2012).

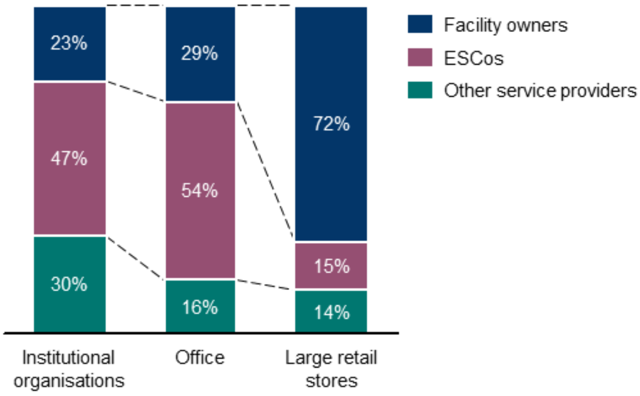


Fig. 5-9. Applicant types in priority sectors of NYSERDA Existing Facilities Programme by project number (2008-11)

Besides technical support, assistance in project financing is another type of support. For example, for the NYSERDA Existing Facilities Programme, research finds that energy service providers taking part in the scheme, compared with those not, are statistically more likely to provide financing assistance, energy audits and coordination of programme incentive (Navigant, 2012). This suggests the important contribution these services can make to savings-based projects, including selling them to customers. Regarding the type of financing assistance, partnership with banks to offer loans (82%) was cited as a more common type of service than energy performance contracting (61%). Even though this indicates the potential role of energy performance contracting, it shows that the financial and project arrangement as in energy performance contracting is not essential for promoting SBI projects.

For SBI schemes, energy service providers are also important partners in areas like technical review and quality control of projects, particularly for complex ones, and provision of M&V (e.g.

ECONOLER and Cadmus, 2015). Another area is the complementarity of energy service providers and the scheme in promoting savings-based projects. It can be seen from two aspects at least. First, with their knowledge of the efficiency upgrade market, energy service providers are well positioned to help identify customers with technical and financial potential for SBI projects (e.g. Rearch Into Action, 2011). Sometimes this involves tailored 'pitches' to appeal to unique customer needs, or preliminary savings estimate to justify further steps in project development (e.g. detailed audits). Second, by engaging in the design stage (e.g. technical analysis or project scoping), energy service providers have an additional leverage to influence projects, by recommending larger projects or measures not proposed by customers, particularly those eligible for savings-based funding (e.g. Nexant, 2014).

These two aspects underscore the 'catalyst' role third-party energy service providers can play. This is highly valuable for schemes whose resources could only allow a 'broad-brush' approach to marketing and customer engagement. To support this type of partnership, many schemes offer accreditation and training to energy service providers to drive the knowledge of application process and to ensure a good quality of service. In return, by being an accredited partner or showing the successful experience with savings-based projects, the affiliations with SBI schemes lends credibility to energy service providers, supporting their marketing of savings-based projects (Rearch Into Action, 2011).

5.6. Conclusion and policy implications

This study empirically examines schemes in North America and Europe with a savings-based approach to offer financial incentives for encouraging electric efficiency investment. It focuses on key designs and their success in supporting electric efficiency and synthesises their value and limitation. It identifies 124 SBI schemes directly facing customers – 95% of them employ pre-set incentives, while only 6 use competitive auctions to determine and allocate incentives. SBI schemes can make valuable contributions, especially by acquiring efficiency opportunities not accommodated by prescriptive schemes. For ten of the non-residential energy efficiency portfolios reviewed, SBI schemes have made up more than 30% of cumulative annual energy savings. Moreover, in terms of cost in saving energy, evidence shows that (Section 5.5.2) SBI schemes can be similar to other non-residential efficiency schemes.

SBI demonstrates its potential in promoting efficiency projects of varying sizes in different customer segments. Yet there is a tendency to use the savings-based approach for non-residential sectors, and in many cases for customised projects or those above a certain size (e.g. energy savings, areas affected). This suggests the benefit of a savings-based approach in being flexible to fit with diverse project and customer needs, in a way conducive to innovation in project design and responsiveness to market changes. However, the need to ensure project quality and efficient scheme operation means that only a subset of efficiency opportunities would benefit from SBI. A strong business case must exist to put forward a project, considering the complex participation and M&V. Small organisations with limited internal resources may well face challenges. For residential customers, the viability of savings-based approach remains largely unproven. Unlike the policy rationale implied in the EDR Pilot in the UK, a flexible savings-based approach may not necessarily be able to capture *all* electric efficiency opportunities in the market.

Thus, for achieving higher electric efficiency targets, while it is valuable to introduce SBI, their position is to complement rather than replacing prescriptive incentive schemes. To support the participation of small organisations, participation and M&V rules should be streamlined to minimise project management burden, while ensuring project quality and M&V reliability. The role of aggregators should be encouraged.

As for the incentive structure, although schemes relying on auctions tend to favour low-cost projects, others featuring pre-set incentives show some flexibility in structuring the incentive. In fact, 37% of the latter use differentiated incentives to strengthen the support for costlier efficiency measures or projects promising deep savings or affecting multiple end-uses/systems. Moreover, 13% of them set requirements for minimum number of affected end-use categories or maximum savings or incentives for certain end-uses. These features reflect the rationale to accelerate electric efficiency acquisition, mainly from diverse end-use categories and comprehensive projects.

SBI schemes can help promote non-lighting electric efficiency opportunities. This depends on several factors like economic case and feasibility, faced by customers, of non-lighting efficiency measures or comprehensive projects, specific design features (e.g. incentive structure and M&V), and relationship with other schemes.

By contrast, there is limited evidence that using a savings-based approach alone may not necessarily encourage comprehensive projects. The process evaluation reports of reviewed schemes point to economic case (e.g. structure of incentive, upfront costs and payback), and motivation and expertise for comprehensive project design, as likely barriers. Strong incentives, or regulatory requirements, for comprehensive projects may help stimulate these projects but a trade-off is needed to avoid undue project management burden on participation. Moreover, additional policy provisions are needed to support comprehensive projects under a SBI scheme, by addressing high upfront cost (e.g. financing, capital access) and offering audit and technical assistance to customers for raising awareness and motivation for comprehensive retrofits.

Finally, the energy service industry is vital in supporting SBI schemes. For customers, the support can be technical assistance or project financing. For the scheme, energy service providers are important partners for technical review, project quality control, marketing and customer engagement for comprehensive energy efficiency projects. Therefore, it is a policy imperative, well aligned with the implementation of SBI schemes, to strengthen the technical and business capability of an energy service industry, given its enabling role in this area.

6 | Paper 3 Forward capacity market to promote electricity use reduction in the residential sector? A case study of the potential of social housing participation in the Electricity Demand Reduction Pilot in the UK

This paper complements Paper 2 in exploring the potential of a savings-based approach for giving financial incentives, as employed by the EDR Pilot, in driving investment in electric EE in the residential sector. Paper 2 and Paper 3 are two strands of analyses to scrutinise H2.

6.1. Abstract

The residential sector is key for electricity demand in many developed economies. Reducing electricity use in households is valuable for carbon mitigation and capacity adequacy, and for addressing fuel poverty. In many liberalised systems, a forward capacity market is established to remunerate resources' capacity value, with some allowing electricity use reduction to participate. This paper focuses on the Electricity Demand Reduction Pilot in the UK that trials a novel approach of incentivising electric efficiency via the Great British Capacity Market. Using a case study of social housing, it identifies barriers faced by the residential sector to utilise funding from the Pilot. While opportunities exist for electricity use reduction in lighting, appliances and heating, financial incentives based on the impact on system peak demand are unlikely to be attractive and disadvantage insulation and efficient heating system. Limited budget for electric efficiency project and inflexible requirement of over two-year payback of EDR Pilot poses the challenge of funding projects, especially for small organisations, even if they can deliver capacity value to the electricity system. The obligation to deliver and verify committed peak savings, and limited scope for payback present challenges and risks for projects to target potential opportunities within households. For communal electricity use, the minimum savings, cash-flow and limited internal capabilities are constraints. Therefore, it is inadequate to rely on a forward capacity market as a

primary vehicle for incentivising electric efficiency investment in the residential sector, highlighting the importance of alternative provisions like supplier obligation and market transformation.

Key words: electricity use reduction; peak demand; capacity market; residential; social housing

6.2. Introduction

In many developed economies, the residential sector is important for electricity use. In the UK, households accounted for 34-37% of the final electricity use[61] during 2000-15 (Fig. 6-1). Its contribution to the system peak demand, typically occurring in 4-8pm of winter weekdays, is proportionately higher – the share is estimated at ~40-45% (Brattle Group and Sustainability First, 2012; Darby and McKenna, 2012). With the projected electrification of heating and transport, the total electricity use and peak demand of households may further grow (Eyre and Baruah, 2015).

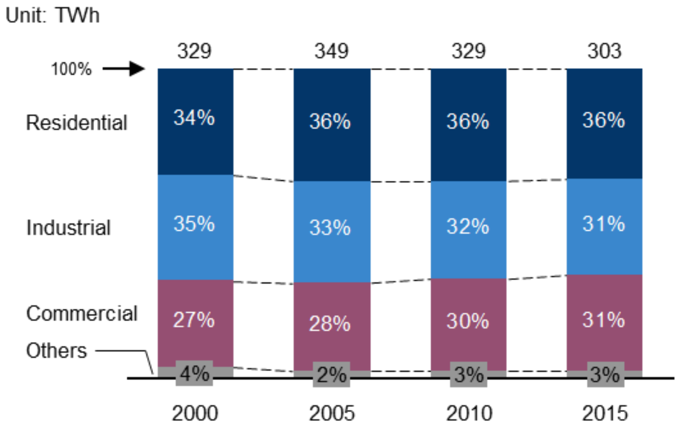


Fig. 6-1. Final electricity consumption in the UK by sector (2000-2015)

Source: BEIS (2016a)

---

[61] Includes final electricity consumption in households, industry, commercial, public administrations and other sectors

Electricity use reduction, i.e. savings in *overall* use from a counterfactual baseline, by conservation or investment in electric efficiency measures[62], has several benefits. First, in 2014, the power sector contributed 31% of the carbon emissions in the UK (BEIS, 2016a; DECC, 2016a). Thus, electricity use reduction is key to carbon mitigation of the UK. Second, with its potential to lower system peak load, electricity use reduction can contribute to capacity adequacy as a cost-effective alternative to generation (e.g. Boardman, 2014; Strbac, 2008). It can also ameliorate the distribution network congestion potentially caused by the proliferation of distributed generation and electric vehicles (Bilton et al., 2014). Third, measures that can lower electricity use may also help tackle fuel poverty. For an average household in the UK, electricity bills constitute roughly 46-53% of energy expenditure over 2001-15 (BEIS, 2016a); for fuel-poor households more likely to rely on electric heating as the main heating source (Ofgem, 2015), the share of electricity in total energy expenses would be higher. Reduction in electricity use would make meaningful impacts on energy bills.

This paper focuses on electricity use reduction from investment in efficiency measures. As in DECC (2013b), the technical potential for electricity use reduction in the UK would be 32.2TWh or 9% of the projected demand in 2030, with 13% from appliances and products in households. It is a conservative guess, since the analysis does not cover any potential in lighting, electric heating and insulation for electrically heated residential properties, which may be large with the penetration of electric heating (Eyre, 2013b).

To incentivise investment in efficiency measures, a mix of policies are created like financial incentives, financing support (e.g. preferential loans), building and product standards, information (e.g. energy labelling) and feedback, and tax (Rosenow et al., 2016a), as well as dedicated funds or professionals training scheme on the national level (EC, 2013). These policies typically interact with each other to bear on outcomes (e.g. energy/peak-savings, cost-effectiveness) (Doris et al.,

---

[62] Electrical equipment with higher efficiency ratings or other measures (e.g. process improvement, insulation) that can help reduce electricity use

2009; Eyre et al., 2015; Nadel et al., 2015). Of them, financial incentives play a salient role[63] – it can be seen theoretically and empirically. First, by reducing the upfront cost and payback, financial incentives are seen as key for addressing market barriers of efficiency investment (e.g. split incentive or high hurdle rate) (de la Rue du Can et al., 2014; Hausman, 1979; Houston, 1983). They also strengthen the market pull for more efficient measures, supporting market development and transformation (e.g. Boardman, 2012b; Green Alliance, 2012; Nadel and Latham, 1998; Rosenberg and Hoefgen, 2009). Second, in Europe, financial incentives (e.g. grant, rebates) are common to promote building and product efficiency (Rosenow and Eyre, 2015; Rosenow et al., 2016b). In the US, over 50% of the utility efficiency obligation programme expenditure was for customer incentives and rebates over 2011-15 in New York and states served by ISO New England (ISO-NE), many of which top the league table of the American Council of an Energy-Efficient Economy (e.g. Massachusetts, Vermont) (NEEP, 2016).

Provision of financial incentives is typically of a regulatory nature. For example, for the utility efficiency obligation programmes, the level of and/or eligibility for financial incentives is determined, administratively or by competitive processes (e.g. 'white certificates'), within the constraints of policy objectives (e.g. budget, savings targets, customer segments to target) set for electricity savings (IEA, 2017). In many places with a restructured electricity market, while the concept of electricity saving as an alternative to generation is hardly new, the provision of financial incentives for efficiency measures is not integrated in wholesale markets and does not directly compete against the acquisition of other electricity resources (SPEER, 2013). However, as forward capacity markets are being established in many jurisdictions, some of them allow electric efficiency measures to take part in capacity procurement auctions alongside other resources like generation or demand response (e.g. PJM, ISO New England), and to get remunerated for their verifiable peak savings (Liu, 2017). In essence, this presents a novel

---

[63] For successful programmes, other aspects of financial incentives programmes (e.g. design and implementation, delivery) are also key.

approach for providing financial incentives for electricity saving, not from regulatory processes but *directly from competitive electricity markets*.

6.2.1. Electricity Demand Reduction Pilot in the UK

In the UK, the Electricity Demand Reduction (EDR) Pilot was created in 2014 to test whether a forward capacity market could be a primary vehicle for incentivising investment in electric efficiency (DECC, 2014a). The EDR Pilot offers funding to organisations in GB for projects that can reduce peak demand by installing electric EE measures[64]. Customers need to propose projects to install electric efficiency measures and are paid based on their peak savings. These projects should deliver verifiable peak savings over 4-8pm of working days of November-February.

The EDR Pilot has two objectives. First, it tests the feasibility of integrating electric EE in the GB Capacity Market DECC (2014a). That said, the EDR Pilot aims to explore the feasibility of incentivising electric efficiency projects by allowing them to bid peak savings into the forward capacity market, which is established in many restructured markets to remunerate resources for the capacity value and ensure resource adequacy (e.g. Gottstein and Schwartz, 2010; Liu, 2017). Different from demand response that focuses on short-term change in load and is dispatchable[65], peak savings from electric efficiency measures are non-dispatchable (FERC, 2009; Liu, 2017). In the newly-created GB Capacity Market, demand response is eligible, but peak savings from electric efficiency measures are not. Therefore, the EDR is set up as a separate scheme but allocates budget in a way like the GB Capacity Market. It is open to various technologies and customer sectors, including the residential sector.

Second, an implicit objective is to examine whether the forward capacity market would be adequate as a *primary* vehicle to incentivise electric EE, without a need of additional regulatory provision of financial incentives. It is seen in the policy consultation that decides on using a

---

[64] Consistent with earlier definition, fuel switching, distributed generation, demand-side response (DSR) or purely behavioural measures are *not* eligible for the EDR Pilot.

[65] In response to instruction of system operator or market pricing signal

forward capacity market to provide necessary financial incentives for electric EE (DECC, 2013a), and the requirement of projects not receiving funding from other government schemes.

A total of £16m was budgeted for two auctions of the Pilot, i.e. auctions in 2015 (£10m for delivery in 2015-16) and 2016 (£6m for delivery in 2016-18). Application for these two phases is now closed. A more detailed description of EDR Pilot can be found in Fig.6-2.

Step 1: **Register Interest**	▪ Organisations register online their interest in participation ▪ Registration does not mean obligation to proceed the application ▪ Registration does not test eligibility of projects or organisation proposing them
Step 2: **Application**	▪ Organisation provides details about project(s): - Measures to install - Measurement & Verification (M&V) Plan - Proposed peak demand reduction - Payback period of project ▪ Organisation can leave up to 40% of proposed peak demand reduction unspecified at this stage ▪ Organisation can submit multiple projects if each project meets eligibility requirements ▪ After application, DECC notifies organisation of whether project(s) are eligible
Step 3: **Bid into the EDR Auction**	▪ For each project, organisation can bid up to the peak demand reduction (kW) proposed in the application, if the 50kW minimum peak demand reduction is met ▪ For each project, organisation specifies the bidding price for unit of peak demand reduction (£/kW), up to £300/kW ▪ Once bidding is closed, auction selects projects from those with lowest bidding price first, until the auction budget is reached
Step 4: **Participant Agreement**	▪ Successful projects will sign agreement to finalise: - Committed peak demand reduction (kW) - Payment level for unit peak demand reduction (£/kW) - Requirement to provide M&V evidence to prove the delivery of peak demand reduction (kW) ▪ Maximum total payment is the product of committed peak demand reduction (kW) and payment level (£/kW)
Step 5: **Installation**	• Organisation installs measures as per the participant agreement and provides their operational verification. • If part of committed peak demand reduction is unspecified in application stage, organisation should confirm the nature of measures to meet the unspecified obligation and the M&V Plan. • If needed, organisation can request to revise project(s) in terms of type, quantity and location of measures to install. Updated M&V Plan is necessary. However, revised project should meet eligibility requirement and committed peak demand reduction (kW) cannot be changed.
Step 6: **Measurement and Verification (M&V)**	• Submit M&V evidence and report to prove the full delivery of committed peak demand reduction (kW). • For every 1% of shortfall in delivering the committed peak demand reduction (kW), project(s) lose 2% of maximum total payment.

Fig. 6-2. Participation processes for the Electricity Demand Reduction (EDR) Pilot in the UK

The EDR Pilot has the following key design features for providing financial incentives. They are modelled after central designs of the forward capacity market (Section 2.4):

- **Technology-neutral** – projects have flexibility of installing one or more EE measures in: 1) replacement of less efficient measures (e.g. lighting, motors and so on); 2) insulation for electrically heated properties; and 3) building energy management system;

- **Peak demand reduction (kW)** – while the government consultation of EDR was initially for electricity use reduction, the EDR Pilot define project savings as average reduction in peak demand (kW) during 4-8pm of working days of November-February, rather than energy savings (kWh);

- **Auction-based** – organisations submit applications for projects and bid into an auction with peak savings (kW) of projects and a bidding price (£/kW). The auction first selects bids with a low bidding price, until the budget for auction is exhausted; and

- **Savings-based incentive** – projects need to demonstrate peak savings (kW) following an established measurement and verification (M&V) protocol. The financial incentives are based on verified peak savings (kW) and their bidding price (£/kW). Financial penalty is applicable for any shortfall in delivering the committed peak savings (kW).

In terms of eligibility, organisations from *all* sectors connected to the Great Britain Electricity Grid can take part, if the following eligibility requirements are met:

- **Minimum payback period** – costs of buying, installing and delivering electric efficiency measures take at least 2 years to pay back with the savings from lower electricity bills;

- **Minimum project size** – for the 2015 auction, any project needs to deliver at least 100kW of verifiable peak demand reduction (kW) during 4-8pm of working days of November-February. This minimum threshold is reduced to 50kW for the 2016 auction; and

- Proposed **measures not funded by other government schemes**[66].

Two auctions have taken place but their success in incentivising projects is very limited, particularly for those affecting households. First, only 13% and 78% of the budget was allocated in auctions for 2015-16 (£1.3m of £10m) and 2016-18 (£4.7m of £6m) respectively (DECC, 2015d, 2016a). Second, commercial or industrial (C&I) customers appear to have dominated in the scheme. In the auction for 2015-16, 86% of the procured peak savings came from C&I organisations and aggregation companies, with the remaining 14% coming from local authorities. In the auction for 2016-18, only 1% of allocated funding went to local authority projects. *Even if all* such savings from projects led by local authorities were from social housing properties, the share is small considering the importance of residential sector in electricity use.

6.2.2. Research objective

This paper examines the role of a forward capacity market in stimulating investment in efficiency measures that can help reduce electricity use in the residential sector, with a case of how social housing has responded to the EDR Pilot in the UK. More specifically, it aims to scrutinise whether it would be adequate to rely on the forward capacity market as a *primary* vehicle for delivering financial incentives, and whether alternative policy provisions would be needed. Its contribution is three-fold. First, it is the first empirical study focusing on the role a forward capacity market can play in the mix of policies providing financial incentives for electric efficiency. While it is an ongoing debate whether a capacity market is the best response to the resource adequacy issue, especially in a system with high penetration of intermittent renewables (EC, 2016a; Gottstein and Skillings, 2012; Hogan, 2017), many key markets (e.g. PJM, ISO-NE, GB, France) have created forward capacity markets of various designs. An empirical understanding of how electric savings can benefit from the forward capacity market and how it

---

[66] These government schemes include Climate Change Agreements (CCA), Energy Company Obligation (ECO), Green Deal Cash-back or Green Deal Home Improvement Fund in England and Wales and Green Homes Scheme in Scotland, Salix Finance, and Renewable Heat Incentive (RHI). Section 2.3 introduces government schemes supporting electricity use reduction in the UK.

can incentivise electric efficiency investment is key to the debate on the design and implementation of capacity mechanism and energy efficiency policy. Second, it aims to inform the policy promoting electricity use reduction in the UK. Despite its historical achievements, regulatory provision to support residential energy efficiency has recently weakened (see Section 6.2). As noted earlier, the failure of EDR in promoting residential projects imply barriers faced by the sector in participating. Given these, this paper provides empirical evidence for assessing whether changes in design or implementation of EDR, or other policy provisions would be necessary. Third, it contributes to the literature on the design and delivery of financial incentive schemes (e.g. how to structure incentives and the approach for providing them) (de la Rue du Can et al., 2014; York et al., 2013).

Section 6.3 introduces the methodology. Section 6.4 discusses the decision-making of social housing providers regarding energy efficiency improvement. Section 6.5 focuses on the current and future activities for electricity demand reduction in social housing. Section 6.6 discusses key barriers for taking part in the EDR Pilot, before Section 6.7 considers alternative policy provisions. Section 6.8 concludes.

6.3. Methodology

6.3.1. Theoretical and analytical frameworks

Central to incentivising electricity use reduction is removing barriers for energy efficiency investment. There is an established literature on market barriers for energy efficiency investment, which suggests the need of policy intervention to promote socially efficient outcomes (e.g. Blumstein et al., 1980; Golove and Eto, 1996). Different but complementary theories have developed over the years to explain those market barriers or ‘efficiency gaps’ (Sorrell et al., 2000). For example, neo-classical theories assume individual rationality and identify barriers like split incentives, lack of capital, market structure and non-cost-reflecting pricing, hidden costs and risks, as well as market failures like imperfect or asymmetric information (see Blumstein et al., 1980;

Eyre, 1997; Golove and Eto, 1996; Hewett, 1998; Hirst and Brown, 1990). Behavioural perspectives characterise ‘bounded rationality’ (e.g. for organisations, payback rule, budgeting and procedure for operation and equipment replacement), nature of information and inertia for changes as additional barriers (March, 1978; Simon, 1966; Sorrell et al., 2000). Organisational theory notes the salience of structure, power and culture (e.g. knowledge, norms, and daily rituals) in affecting the energy efficiency activities of organisation (Cebon, 1992; Sorrell et al., 2000).

These theories have two analytical implications. First, to examine whether a forward capacity market can be a primary vehicle for incentivising residential electricity use reduction means assessing the extent to which it addresses the barriers faced by key players (e.g. tenants, social landlords) in electric efficiency investment. Second, for social landlords, the organisational decision-making process (e.g. motivations, rules and practice) and priority, and their interplay with efficiency improvement opportunities and external funding sources, sets the context to assess the value proposition of a forward capacity market (Capon, 2004; Reeves, 2011). It is indispensable for analysing whether and how the design and requirements of a forward capacity market (as represented by the EDR Pilot) removes barriers for electric efficiency investment in the residential sector. Thus, this paper comprises of three interlinked analytical components based on empirical findings from the survey and semi-structured interviews:

- *How decisions are made regarding electric efficiency investment in social housing (Section 6.4)* – it focuses on the motivations and key criteria of social landlords in appraising and implementing energy efficiency projects.

- *What priority areas are to improve electric efficiency and access funding (Section 6.5)* – based on Section 6.4, it examines the key opportunities of electricity use reduction and importance of government funding as seen by social landlords, as well as any barriers for electric efficiency investment.

- *Whether the EDR Pilot removes the barriers for electric efficiency (Section 6.6)* – drawing upon Section 6.4 and 6.5, it assesses whether the EDR Pilot would provide attractive financial incentives to key opportunities as seen by social landlords and help address the barriers.

6.3.2. Case study of the EDR Pilot

This study focuses on the social housing in GB as a case study, for three reasons. First, social housing, provided by housing associations and local authorities, makes up a notable part of residential properties in GB – as shown in Fig. 1, in 2014-15, social housing contributes around 20% of residential dwellings in GB, with the share even higher in London (23%) and Scotland (24%). Second, the sector, compared with owner-occupier and private renting, has been more active in achieving higher efficiency levels for housing properties (DCLG, 2016c; Scottish Government, 2016b). The engagement with general energy efficiency issues, and prior experience of undertaking projects to improve efficiency levels in residential properties (e.g. for compliance with the Decent Homes Standard), mean that social housing providers may have potential to participate in the EDR Pilot. Third, since social housing providers own or manage properties, they could act as an 'aggregator' for electricity use reduction from households and offer it in the EDR.

An online survey was carried out during January 2016-January 2017 with registered social housing providers to understand project experiences of installing efficient electrical equipment or insulation for electrically heated properties (e.g. type of measures, funding, and evaluation), plans for projects that can help reduce electricity demand, and engagement with the EDR. Lists of registered social housing providers in GB were retrieved from Homes and Communities Agency (for England), Scottish Housing Regulator and Welsh Government in November 2015. Survey invitations were sent to 1,554 organisations (i.e. 75% of 2,062 on the lists) whose general email addresses or website inquiry facilities were publicly available.

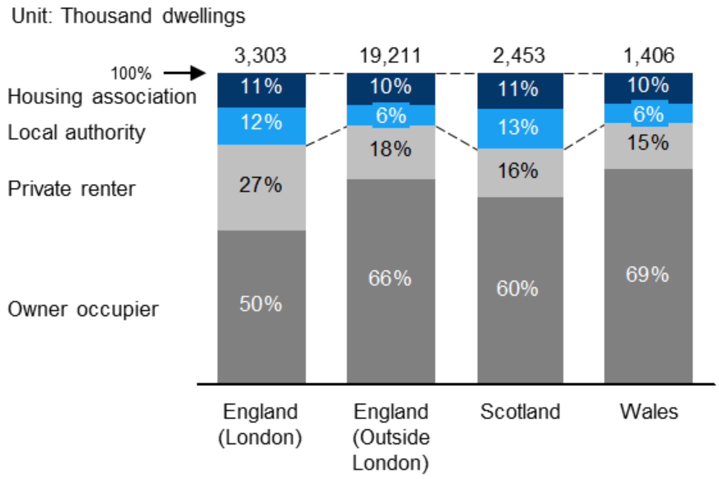
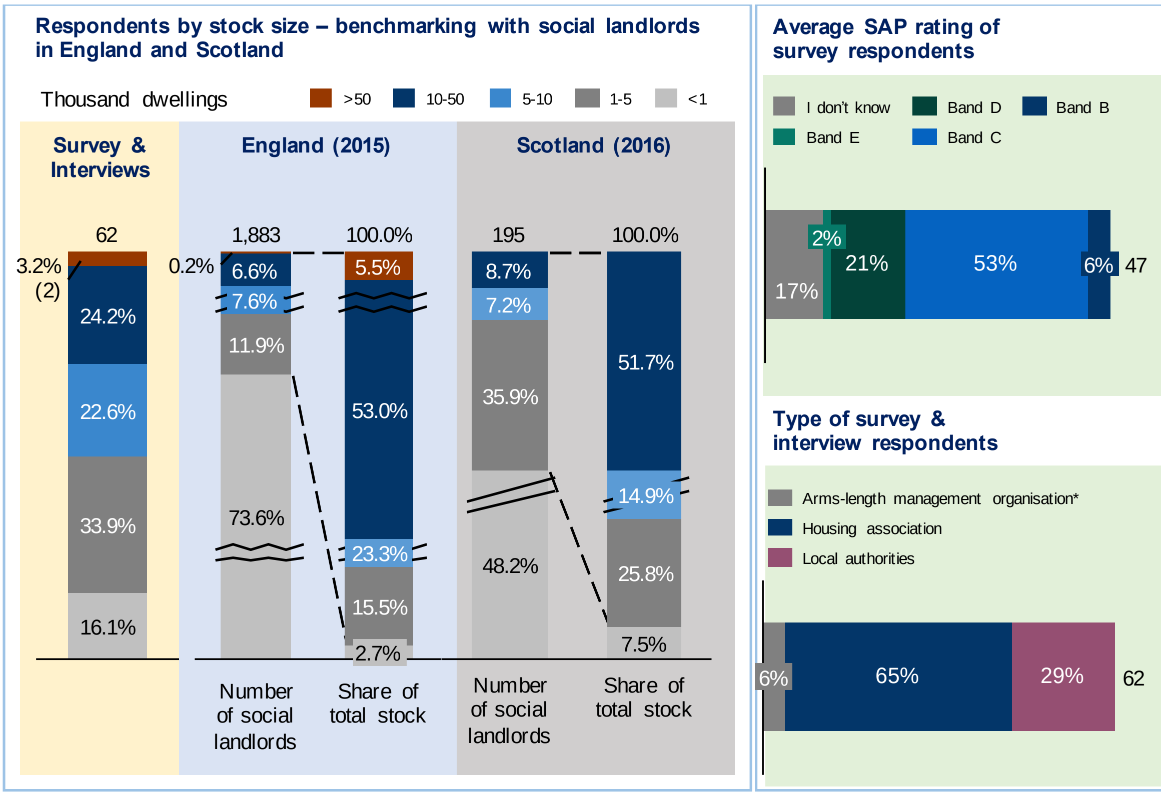


Fig. 6-3. Share of social housing properties in residential dwellings in GB (2014-15)

Source: DCLG (2016a); Scottish Government (2016a); Welsh Government (2016)

To complement the online survey, semi-structured interviews were conducted with registered social housing providers for in-depth discussion on the planning and funding of projects to install efficient electrical equipment or insulation for electrically heated properties, and opportunities and barriers for participating in the EDR Pilot. Invitation was made at the end of online survey and through ‘cold calls’ with registered social housing providers. If the social housing provider interviewed had not completed the online survey, these questions were included in the semi-structured interview. A topic guide is prepared with key questions and conversation points. The sample topic guide can be found in the Annex. Consent for recording is obtained for all interviews, which are transcribed. NVivo is used to code transcripts based on themes as they emerge from interviews and later analysis.

In total, the online survey received 47 responses and 24 semi-structured interviews, which averaged 0.5-1 hour in duration, were conducted. All respondents are responsible for energy-related issues (e.g. asset management, energy efficiency), with many of them in managerial positions. Since nine of them participated in both the survey and interview, this research is based on the inputs from 62 respondents. As shown in Fig. 2, 84% of these respondents have over 1,000 dwellings in ownership or management. In England and Scotland, which account for over 90% of social housing in GB, social landlords with over 1,000 dwellings are responsible for most of the properties, meaning that the inputs of respondents to this study would be highly relevant regarding the overall properties. Respondents' organisations are typical regarding efficiency levels – 60% of them have an average SAP rating[67] over Band C (69-80), whereas the mean SAP for social housing properties in England and Scotland is around 66-68 in 2014 (DCLG, 2016c; Scottish Government, 2015). Respondents came from housing associations and local authorities. More anonymous details about interviewees can be found in the Annex.



*Arms-length management organisation is typically set up by local authorities to manage and improve their housing stock (e.g. provision of housing services), while the ownership remains with local authority

Fig. 6-4. Respondent characteristics: stock size with benchmarking, average SAP rating and type of organisation

Source: DCLG (2017); HCA (2015); Scottish Housing Regulator (2017); Own survey

---

[67] Standard Assessment Procedure is a methodology used by the UK government to assess and compare energy and environmental performance of buildings.

6.3.3. Research limitations

There are several limitations. First, while the sample mainly consists of large social landlords playing key roles in the social housing market, the relative small number of respondents means that it is beneficial for future research to examine whether the findings would be applicable to other types of social landlords, particularly those in a different market or regulatory environment. Second, the survey and interviews were carried out after the two EDR auctions completed. Given the novelty of EDR, this research strategy allows respondents to reflect on key aspects of their engagement with the pilot, after they gain more experience with it. However, the lag could have the risk of not capturing all the considerations as emerging from the application process. To reduce the risk, the semi-structured interviews are designed to guide participants to revisit and reflect on the specific process of their engagement and decision-making.

6.4. Decision-making for energy efficiency improvement in social housing

6.4.1. Motivations for energy efficiency projects in social housing

Understanding the major drivers for efficiency projects in social housing provides the context for considering the importance and priority of electricity use reduction. For past projects, as shown in the survey (Fig. 6-4) and interviews, motivations for installing efficient equipment and measures seem to be multi-faceted. First, regulatory requirements for new build (e.g. building regulation) and existing stock, including the Decent Homes Standard in England, Energy Efficiency Standards for Social Housing in Scotland and Welsh Housing Quality Standard Programme, mean that a minimum level of efficiency or Standard Assessment Procedure (SAP) rating must be achieved for social housing properties. As one respondent commented:

> *'Our improvements are more based around external insulation, boiler and window upgrades to… meet the Decent Homes Standard. We are looking at the basics in terms of upgrades.'*

- SHP [6] a housing association with 5,000-10,000 homes

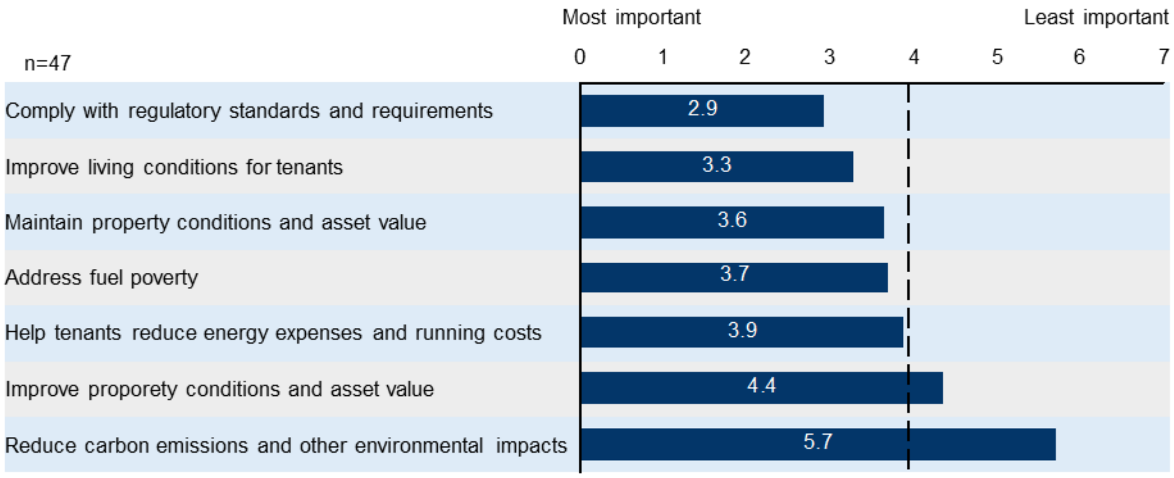


Fig. 6-5. Average ranking scores of motivations to improve energy efficiency in existing social housing properties

Source: Own survey

Second, delivering tenant benefits is also a key driver. If practically possible (e.g. available funds), many interviewees mentioned going beyond the regulatory requirements to improve the efficiency of social housing. It is mainly for helping tenants reduce energy expenses, particularly for low-income ones and thus lowering the risk of rent arrears, and for addressing fuel poverty – many interviewees commented that this had to do with the ‘moral’ obligation of social housing. For communal area, while tenants are not directly responsible for its energy use, energy savings from installing more efficient equipment (e.g. lighting) might be passed on to tenants through reduced service charge.

Besides economic savings, improved living conditions (e.g. quality of lighting and heating) are another type of tenant benefits. For example, respondents mentioned the issue of ‘under-heating’ where tenants inadequately heat their properties, with electricity or other fuels, to manage the energy spending – this can lead to health problems. In this case, measures like insulation may not lead to lower energy use *per se* but can help keep heat and raise comfort level in the property for winter.

Third, related to tenant benefits, social landlords appear to see efficiency measures as part of asset management to maintain or increase the property value or to lower cost of maintenance. On one hand, by investing in certain efficiency measures, especially those affecting energy use for which tenants are directly responsible for, organisations would expect to improve the property condition (e.g. aesthetics or running costs) and the attractiveness to renters, thus reducing tenant turnover or voids. Many social landlords set targets of average SAP of properties for their asset management practices.

> *"We are not an energy-payer…the payback for us is that tenants may stay in the house for longer – they become more lettable or may be able to pay their rent due to reduced energy bills."*
>
> \- SHP [20], a housing association with 10,000-50,000 homes

On the other, some efficiency measures (e.g. LED, efficient window) may have an extended operational lifetime. For social landlords, it means lower frequency of equipment replacement and reduced costs of maintenance (e.g. labour).

Lastly, few interviewees mentioned environmental impacts like carbon emissions were a key driver – these tend to be large social landlords, with some certified by standards of environmental management (e.g. ISO14001). This is consistent with the online survey that shows environmental impacts, compared with other motivations, are a less salient driver.

6.4.2. Identification of opportunity and project appraisal

For identifying opportunities for efficiency improvement, interviewees mentioned using the survey of stock conditions, which may record information about properties such as SAP rating, insulation type, equipment or appliance – particularly those provided by social landlords – and main heating source. So, in the case of replacing specific equipment (e.g. electric storage heaters) or improving the average SAP rating of stock, organisations would be able to identify individual properties or buildings to target. As the stock survey may not be up to date or comprehensive in property coverage, in many cases, additional efforts (e.g. sampling) are often necessary to inspect properties or equipment, for refining the scope and schedule of efficiency improvement.

Social landlords tend to develop a long-term perspective (e.g. 20 years) for efficiency improvement or property management. For example, for equipment (e.g. heating system, boilers, communal lighting), its replacement depends on the depreciation and occurs in cycles, or ‘phases’ across the stock. It often runs on a ‘like-for-like’ basis in terms of technology choice but can provide an opportunity window for contemplating upgrades to higher efficiency, in a similar way with significant electrical work.

Largely in line with the long-term strategy, each year, plans for projects to improve efficiency levels or conditions of properties are made. In choosing project initiatives to pursue, there are three key factors. First, organisations would consider projects given the investment needs and available budget, or rather the feasible scale of initiatives given the financial resources. Since the available funding is finite, trade-offs between project initiatives are inevitable, to maximise impacts in priority areas (e.g. raising SAP rating, tenant benefits like fuel poverty reduction).

Social landlords typically dedicated a part of rent revenues, as a budget for improvement or capital investment, for equipment replacement, repairs and property maintenance. Some of them also ‘recycle’ proceeds from schemes like Renewable Heat Incentives or Feed-in Tariffs to feed into such a budget. This internal budget dictates the nature and scale of improvements, including interventions that can be carried out in a year – some organisations may even have formal internal competition for such funding. At the same time, respondents mentioned that they would explore external funding, from government and third parties, when planning for energy efficiency projects – sometimes projects need to be adjusted to meet requirements of external funding (e.g. type of measures).

Second, cost-benefit is a key factor. Organisations would compare the costs against outcomes like savings in energy use or maintenance costs, and reduced voids or rent arrears that can be attributed to the efficiency improvement in properties. In other words, return on investment or net present value of any project initiative is considered. For example, one respondent noted that their LED projects had achieved high energy-savings, making it unnecessary to seek external funding to justify its business case. As for equipment replacement, while it typically occurs based on the depreciation, it could be pulled forward if there is a strong business case.

> *"Normally we would not pull forward but where we know ongoing maintenance costs associated with communal lighting, we can pull forward and say actually it is cheaper to take it all out."*

- SHP [14], a housing association with 1,000-5,000 homes

However, one interviewee also mentioned the possibility that if budget would be available, efficiency measures might be installed to deliver savings to tenants, even if the social landlord would not earn a financial return directly.

Third, a few practical issues are also important considerations. Social landlords need assurance that technical performance of efficiency measures can deliver benefits, especially for measures with which organisations do not have much experience. Many interviewees noted that they would try to 'bundle' planned interventions into one project, rather than treating each type of intervention 'in isolation'.

6.5. Electricity use reduction in social housing: focus, opportunity and practical consideration

6.5.1. Activities of projects affecting electricity use

As shown by the survey, of projects to improve energy efficiency in social housing properties, there appears to be a focus on efficient heating systems (e.g. boilers) and insulation measures (e.g. wall insulation, window upgrade). In many cases, these measures mostly affect gas consumption rather than electricity use, unless the house is electrically heated. As per the survey, for each common electricity end-use (e.g. lighting, appliance), most of respondents (>70%) installed efficient measures in only <20% of the energy efficiency projects in the past five years (Fig. 6-5). More efficient appliances, air-conditioning, mechanical ventilation, electrical water heating and electric motors are least likely to have been installed by social landlords, with >66% of the respondents citing that none of the previous projects included them. Nevertheless, there are some activities of projects installing insulation for electrically heated properties, efficient lighting in communal areas, and to a less degree, lighting in tenants’ dwellings and heat pumps.

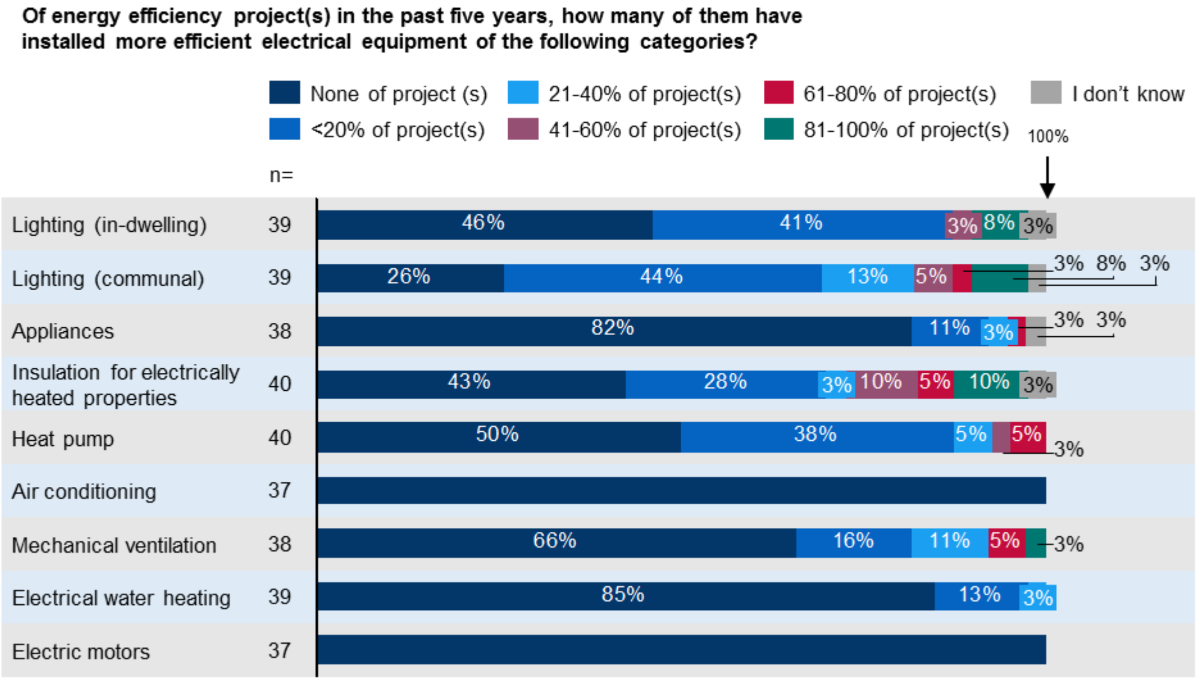


Fig. 6-6. Project activities for electricity demand reduction in social housing

Source: Own survey

This pattern is consistent with the findings of interviews where almost all organisations mentioned a focus on heating, including heat pumps, and insulation. Some of them carried out initiatives, although in relatively small scales, to install efficient electrical equipment such as LED lighting or electric motors in social housing. Such initiatives can take many forms from ‘free give-outs’ of efficient light bulbs to replacement of communal or exterior lighting to LED. Moreover, many interviewees also mentioned efforts to move properties on electric storage heating to gas heating, and some projects installing solar PVs, notably on the roof of large communal buildings.

The focus on heating and insulation measures can be explained by the motivations to deliver tenant benefits and improve property value. First, heating is one main source of energy use and expenditure in the residential sector overall in the UK (Fig. 6-6). For houses, on average, about 84% of gas use and 23% of electricity consumption was for space heating in 2015 – it constitutes 70% of energy use in households (BEIS, 2016b). In terms of expenditure, based on the statistics of Fig. 6, it can be calculated that space heating was responsible for 53% of total energy bills on average in 2015. Considering this, efficient heating and insulation are more relevant options for helping tenants keep warm and reduce energy expenses. As noted by interviewees, the approach is typically ‘insulation first’ and if possible, they would consider changing heating systems at the same time – for electrically heated properties, it means switching to gas or installing heat pumps. Thus, non-heating electricity use (e.g. lighting, appliance) is a secondary priority in general.

> *“Insulation is a magnitude more important…the proportion of service charge due to electricity of a few lights is absolutely miniscule compared with heating costs.”*
>
> \- SHP [13], a local authority with 10,000-50,000 homes

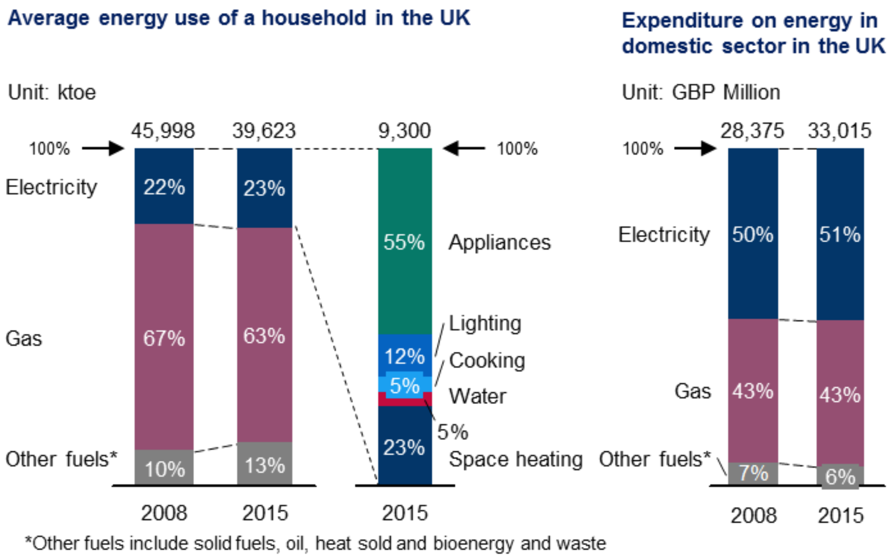


Fig. 6-7. Energy use and expenditure of residential sector in the UK (2008 and 2015)

Source: BEIS (2016a, b)

Second, largely because of the salience of heating in terms of energy use, interviewees noted that improving insulation is most effective in raising the SAP ratings of properties, for instance as required by the Decent Homes Standard or similar regulations in the devolved administrations.

Considering this, more efficient heating (e.g. heat pump) and insulation for electrically heated social housing may well make great impacts in electricity use reduction in this sector. Across the UK, electrical heating has declined in its popularity. The share of homes relying on electric heating is down from 27% of all residential dwellings with central heating in 1970 to 6% in 2014, with 89% of them being installed with electric storage heaters (BEIS, 2016b). By contrast, the penetration of storage heaters is higher in social housing, with its share of social-rented households 11% for registered providers in England and 22% for housing associations in Scotland (Ofgem, 2015). However, as mentioned by some interviewees, there is a trend of installing electric heating (e.g. panel heater) in some new builds with a high insulation level, for which it would be economically sub-optimal to install gas heating.

In terms of heating systems, there appears to be a trend of replacing the old storage heaters – while they are intended to use cheap, off-peak electricity to store and gradually release heat, there are issues around the heating quality (e.g. heat release cannot be controlled) and running cost due to higher price of electricity. There are two general directions. First, for properties close to gas network, they would be switched from electrical heating to gas heating, which is cheaper, probably with co-funding from gas network (e.g. National Grid Affordable Warmth Solutions), although for tower blocks this may not be an option due to safety risks. Second, for those off gas network, an alternative would be to replace with heat pumps or alternatives that can provide improved heating services (e.g. panel heaters, new type of storage heaters like Quantum). Moreover, organisations may install heat pumps in houses relying on solid fuel or oil as an alternative to providing improved, affordable heating. For properties in exposed areas, heating ‘top-up’ from other sources (e.g. multi-fuel burner) may be needed in very cold months.

6.5.2. Future opportunities for electricity demand reduction

a) Lighting

Efficient lighting, particularly LED, is seen by most of interviewees as an area with high potential for reducing electricity use. Reasons are two-fold. First, energy-saving lighting (e.g. CFLs) has been available for a long time but in 2015 its share in residential lighting is only 57%, meaning that there is potential of further penetration (BEIS, 2016b). Second, for LED, its wattage is significantly lower than CFLs and its deployment in residential sector is still in the infancy (1% penetration of residential lighting market in 2015).

However, for most of the interviewees, they can only directly address a subset of these opportunities, namely lighting in communal area (e.g. corridors or lift area, for flat tower blocks) and – through system certification – new builds and bathrooms and kitchens within tenants' properties. For communal areas, social landlords are often responsible for the maintenance of lighting systems. Moreover, as they often pay for the electricity use in these areas and then pass the costs to tenants through service charge, they would be able to capture financial savings, thus justifying the business case of investment. As lighting in communal areas tends to be on all the time, the payback for changing to LEDs should be fast.

For new builds, while the regulation does not mandate LED fittings, some organisations mentioned that their role of a developer puts them in a position of deciding technical specifications of lighting. For kitchens and bathrooms within tenant properties, social landlords typically certify the lighting systems, with which tenants are less likely to meddle. Although its low usage leads to a long payback, the long lifetime means less need for maintenance – as one respondent puts it, it is 'almost a cost-saving to residents not having to replace lamps'. However, electrical work (e.g. rewiring) may be necessary and access to properties while occupied can be a constraint. The replacement can be done during vacancy before properties are re-let, which tends to affect a small portion of stock – as a proxy, in England, only 4% of the social housing stock were classified as vacant in 2014 (DCLG, 2016a).

However, organisations tend to have a limited influence over other lightings within tenants' homes. As respondents noted, for general needs homes, since tenants are directly responsible for their electricity bills, social landlords cannot capture savings from moving to LEDs. Tenants, on the other hand, may find the upfront costs of LEDs prohibitive.

> *"[LED] is a very affluent thing for people to do, like 25 pounds for 5 light bulbs – this is not something tenants in social housing would do."*
>
> \- SHP [19], a local authority with 5,000-10,000 homes

Therefore, while some interviewees expressed an interest in replacing lighting within properties with LED, it may not happen without access to some funding sources. Moreover, there are concerns that installed LEDs, especially those not in recessed fittings, would not remain in use, if tenants remove them and replace with older bulbs.

> *"When you have something hanging down, a pendant, there is always a risk…where you put a bulb in and the bulb would go missing. That bulb costs £10 and it is a waste of investment."*
>
> \- SHP [14], a housing association with 1,000-5,000 homes

b) Electric heating and insulation

Interviewees mentioned a continuing need to improve heating systems (e.g. heat pumps, efficient electric pump or motors for central heating) and insulation of properties that are electrically heated. For some organisations, even if the share of electrically heated properties in their stock is low, they plan to prioritise projects switching to gas or installing heat pumps or insulation, for addressing fuel poverty and vulnerability:

> *"Sheltered housing constitutes about 5% of [our] total stock but 67% of them are electrically heated. Electrical heating tends to be found in areas that are more vulnerable."*
>
> \- SHP [16], a housing association with 10,000-50,000 homes

This proposition is supported by statistics – according to the English Housing Survey 2014, 79.3% of social housing properties with storage heaters would benefit from upgrades in this area (DCLG, 2016b).

Improved insulation for electrically heated properties has the potential to reduce electricity use, although it depends on how residents use their heating systems, especially if properties are under-heated prior to the improvement:

> *"Sometimes they use the same amount of energy because they actually heat the house properly for the first time."*
>
> \- SHP [11], a housing association with 1,000-5,000 homes

c) Appliances

Electric appliances are responsible for the largest share of electricity use in an average household (Fig. 6-6). There is evidence for further efficiency gain in major appliances, given the low penetration of A++/+++ (27.3%) in terms of unit sales (GfK, 2016). However, social housing providers tend to have very a limited influence over the choice of electrical appliances in general needs properties. It is because: 1) appliances are typically brought in by tenants; and 2) general needs are the major provision type – the share is 71% of social housing stock in England in 2015 and 83% in Scotland in 2017 (DCLG, 2015; Scottish Housing Regulator, 2017). Some interviewees mentioned that they would promote appliances with higher efficiency ratings through tenant engagement such as newsletters, visits of energy advisers and campaigns.

Social landlords may provide electrical appliances under supported housing schemes (e.g. sheltered housing), energy ratings of which seem to be driven by regulatory requirements and more importantly, available financial capital. However, even if capital is available, the potential in this segment is limited given the small share of supported housing schemes.

6.5.3. Funding to support future projects

Of respondents to the survey, most of them are interested in project opportunities that can reduce electricity use – 68% of them are either developing or interested in developing such project plans (Fig. 6-7). However, in terms of potential barriers, access to funding is the most common (74% of survey respondents), while other common ones include business case, awareness of opportunities, performance of technologies and practicality of installation and customer engagement.

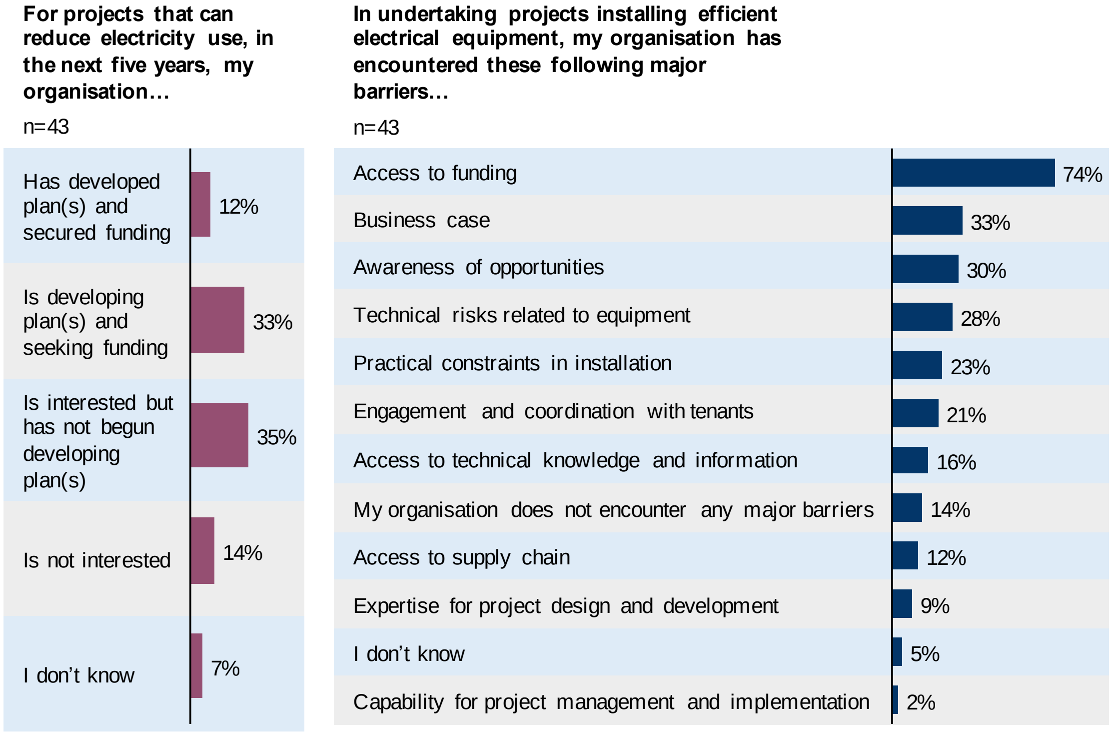


Fig. 6-8. Plans for projects to reduce electricity demand reduction in social housing

Source: Own survey

Social landlords have utilised a wide range of funding schemes to support projects from insulation, ‘whole-house’ retrofit, gas switching, solar PV and pilots to trial new technology (e.g. Quantum storage heaters), although supplier obligation programmes (e.g. ECO, CESP and CERT) are the sources most commonly used (Fig. 6-8). In the survey, 96% of respondents rated government funding as important for energy efficiency projects.

Importance of government funding to projects can be seen in two aspects. First, interviewees noted that government funding or financing programme (e.g. Salix[68]) could contribute to the project economics, thus shortening payback or alleviating the pressure of upfront cost. This is helpful for improvement that goes above regulatory requirements, in which case external funding may be desirable or even needed. Second, having such external funds can help raise the profile for projects in terms of internal budgeting.

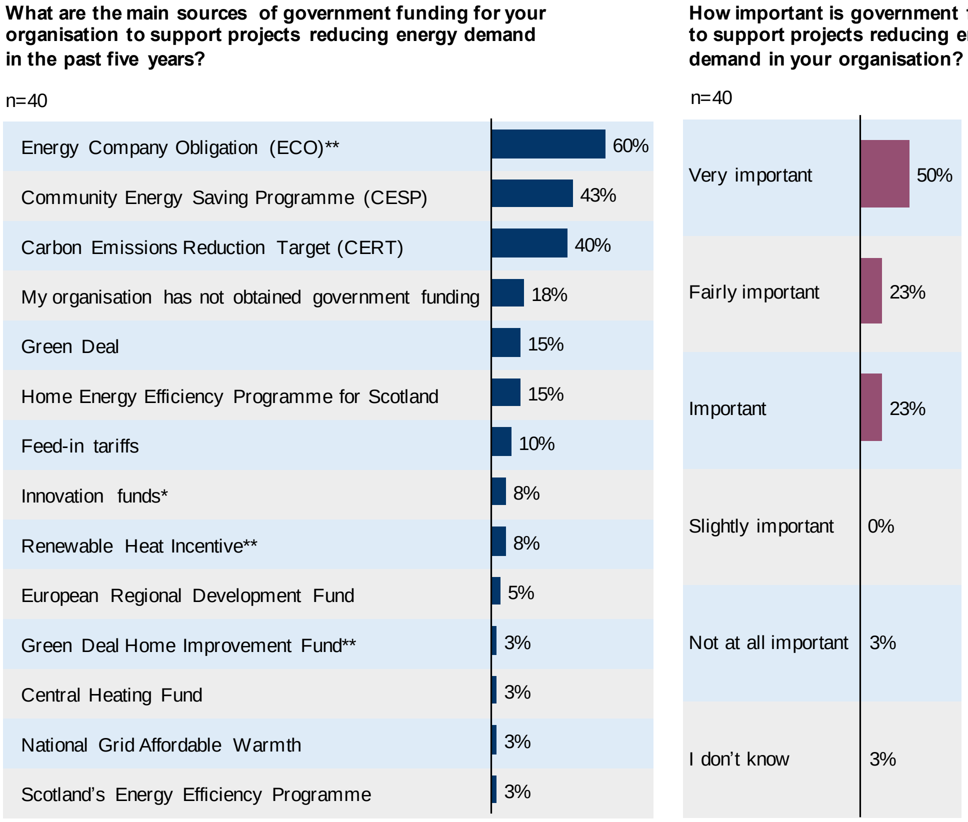
> *“If there is money available, it always increases the interest at the executive level, if we can go to them and say this money would help us fund the scheme.”*
>
> - SHP [3], a housing association with 1,000-5,000 homes

Sometimes government schemes may be a catalyst for organisations to explore opportunities in certain areas (e.g. technologies), although with improved data about properties social landlords could have a more proactive approach for asset management.

> *“Some of what we do is driven by funding, although we do not like just responding in a knee-jerk sort of way for funding. But sometimes that is how it is because you need to have good data to understand your assets and respond to funding opportunities.”*
>
> - SHP [4], a housing association with 1,000-5,000 homes

---

[68] Interest-free loan provided by the UK government to public organisations for undertaking efficiency projects



*Includes National Energy Action Technical Innovation Fund, Retrofit for the Future
**Measures benefiting from these incentive programmes are not eligible for the Electricity Demand Reduction (EDR) Pilot
ECO (2013-present) and CERT (2008-2012): energy supplier obligation programme to promote energy efficiency in the UK; CESP (2009-2012): energy supplier obligation programme targeting low income households; Green Deal: on-bill financing programme for household energy efficiency improvement and is dis-continued in 2015; Home Energy Efficiency Programme for Scotland: initiative of Scottish Government to reduce fuel poverty and improve energy efficiency in homes; Feed-in tariffs are for small-scale renewables like solar PVs; Renewable Heat Incentive: incentive scheme for installing renewable heating technologies (e.g. heat pumps, biomass boilers and solar water heating); European Regional Development Fund: European Union fund to support low-carbon economy as well as other agenda (e.g. innovation, research); Green Deal Home Improvement Fund: cash incentive to help kick-start Green Deal and includes Green Deal Cash-back and Green Homes Scheme in Scotland; Central Heating Fund: capital funding programme to support local authorities to introduce central heating to fuel poor households; National Grid Affordable Warmth: established by National Grid in 2008 to assist qualifying homes in the 25% most deprived areas in England with connection to gas network, central heating system and advice; Scotland's Energy Efficiency Programme: funding programme for local authorities in Scotland to pilot new and innovative approach to energy efficiency in homes, schools, hospitals and businesses

Fig. 6-9. Government funding and its importance in supporting projects to reduce energy demand in social housing

Source: Own survey

However, the changes in government funding regimes appear to lead organisations to rely more on their own funding, with implications for how they engage with government schemes. The ambition of supplier obligation has weakened in the transition from CERT to ECO, and shifted to focus on more expensive solid wall insulation (SWI) and hard-to-treat cavity wall insulation (CWI), and assistance to households in fuel poverty (Rosenow and Eyre, 2013). This abrupt directional change, together with more complicated paperwork and complex nature of measures, caused a sharp decline in insulation installations before the targets were once further trimmed (Rosenow and Eyre, 2015). For social housing, these radical changes reduced the funding for insulation works – interviewees mentioned significantly lower contribution of ECO to project finances, and the planned projects even was cancelled due to shortfall of expected fund to cover transactional costs of seeking it (e.g. consultancy fees for brokers). In a way, this affected the scale and scope of projects, with some organisations having to scale back their efficiency improvement initiatives to minimum for meeting regulatory requirements. Therefore, some have moved to rely their own funding resources – they would seek the government funding when it is available but try not to base investment plans predominantly on that. This means first assessing whether the internal budget can cover the planned efficiency investment. If not, external funding including government schemes is to be contemplated for plugging the gap.

> *"It is better to rely on nothing and build your plan on that basis than thinking that there is going to be something there. These things are not trivial."*
>
> - SHP [21], a housing association with 1,000-5,000 homes

Besides, some organisations are also exploring alternative funding models. For larger organisations, collaboration with energy service companies (ESCos) or other third parties in sharing costs and risks can be beneficial in pushing forward projects (e.g. district heating), especially given shortfalls in budget for upfront costs, if the relationship of different stakeholders can be properly managed. Like the ESCo model, another example is an off-balance sheet model where a third party fully funds the upfront investment and social landlord makes payment on a 'leasing' basis for the efficiency measures, typically for a specific period.

6.6. Engagement with the EDR Pilot and barriers for participation

Of respondents to the survey and interviews, 43% mentioned that they were aware of the EDR Pilot, although only three applied to either of the two auctions. Five barriers were highlighted by respondents for participating in the EDR Pilot.

6.6.1. Availability of funding for upfront investment

Consistent with the survey, organisations – particularly small ones – mentioned lack of funding to support projects as one barrier. It can be seen in two areas. First, as discussed earlier, the internal budget for energy efficiency projects, which comes from the housing rent that is regulated by the government, may well be limited. In England, the rent on social housing has been revised down in recent years. This has exerted downward pressure on the internal budget available for efficiency improvement. Given the secondary salience often given to non-heating-related electricity use, the implication is limited budget to support projects to reduce non-heating electricity demand. This is especially true for improvements in areas (e.g. lighting and appliances in general needs properties) where tenants are directly responsible for electricity bills and social landlords do not earn any return:

> *"There is no plan [to roll out LED to our housing stock]. It is not…viable for now just because of the cut to social housing funding, through the rent cut each year."*
>
> \- SHP [5], a housing association with 5,000-10,000 homes

Second, the EDR Pilot requires a project payback of at least two years and successful projects would receive the first part of payment (i.e. 80% of total expected payment) only after the peak savings over winter months are verified, which is at least 6 months after the equipment installation is operationally verified. While interviews suggest that the acceptable project payback may differ amongst organisations (e.g. from 1 year to 3-5 years), this means that projects paying back faster, thus more attractive, especially to small social landlords, may not get the EDR funding. Moreover, for those with a lower budget for efficiency investment, it also implies issues with financial cash-flow, especially for large-scale projects:

> *"For a small organisation like ours, paying money out and waiting for the two-year payback – it seems a short time but still a big amount of money that would leave us struggle in other areas."*
>
> - SHP [6], a housing association with 1,000-5,000 homes

As one respondent noted, more experience is needed with the funding payment approach employed in the EDR Pilot and a similar programme of Renewable Heat Incentive:

> *"It involves a change of thinking for an organisation like ours because the situation where you have to pay money upfront and then get some money back later is not the traditional way of funding."*
>
> - SHP [8], a housing association with 10,000-50,000 homes

Another interviewee commented on the importance of upfront funding, suggesting an approach where part of payment is made to help with project upfront costs (e.g. preparation and installation), while the rest is subject to savings verification and payment adjustment.

6.6.2. Limited internal resources

Another barrier mentioned is limited organisational resources to seek funding and manage projects under the EDR Pilot. It has two aspects. First, small social landlords are unlikely to have dedicated staff to work on energy related issues (e.g. maintenance or energy procurement). For large organisations that do have such positions for assessing technology options and developing business plans for improvement, the team may be small. For example, a relatively large social landlord, managing over 15,000 homes, has only 2-3 staff members overseeing energy efficiency issues and 1-2 of them are responsible for the project implementation. Competing responsibilities from managing other projects, especially those related to priority areas of heating and insulation, or even routine tasks suggest lack of time to develop knowledge of the EDR and explore any project potentials, especially given its novel nature that does not justify the economic case of dedicating team resources:

> *"In social housing, it is rare that you have a dedicated person to look at energy aspects of work…I remembered looking at [EDR]…it sounds like something too big for me or colleagues to look at."*
>
> \- SHP [2], a housing association with 5,000-9,000 homes

One respondent relying on direct labour to undertake property maintenance also cited the availability of direct labour as a constraint for considering projects outside those already committed (e.g. routine maintenance or planned equipment replacement).

Second, many interviewees aware of the EDR Pilot but not participating cited complicated, thus time-consuming, application process as a major barrier. For some, while competitive bidding is less of a hurdle, due to prior experience with schemes with a similar approach, it is burdensome to gather data from monitoring and provide necessary information to demonstrate peak demand savings, unless external expertise or capability is brought in:

> *"It is very technical, especially in the electrical area of work. Not many housing associations will have the expertise to even think about how you will go about acquiring those figures you would need. You would an electrical specialist to work that out…it is much more trouble than it is worth."*
>
> \- SHP [8], a housing association with 10,000-50,000 homes

> *"[For] the EDR Pilot…resources required for continuing monitoring and review may be limited."*
>
> \- SHP [9], a housing association with 10,000-50,000 homes

One large social landlord with a dedicated energy team made attempts to apply but did not in the end, citing limited internal resources to complete application in time as the reason.

The fragmented social housing sector in GB means most of social landlords are small organisations (Fig. 3). Unless a strong support is available from third parties like equipment suppliers or contractors or the application is simplified, it may well be difficult for social housing to find internal capabilities to utilise the EDR scheme.

6.6.3. Focus on peak demand savings

The EDR Pilot remunerates projects based on the impacts on system peak demand in winter – it is distinctive from savings in total electricity use. Some interviewees commented that the focus on peak demand savings does not align well with their key interest in reducing total energy use. In fact, the issue of peak demand is largely seen as irrelevant to social landlords, except if connection permission needs to be obtained for connecting heat pumps or solar PV to congested distribution networks.

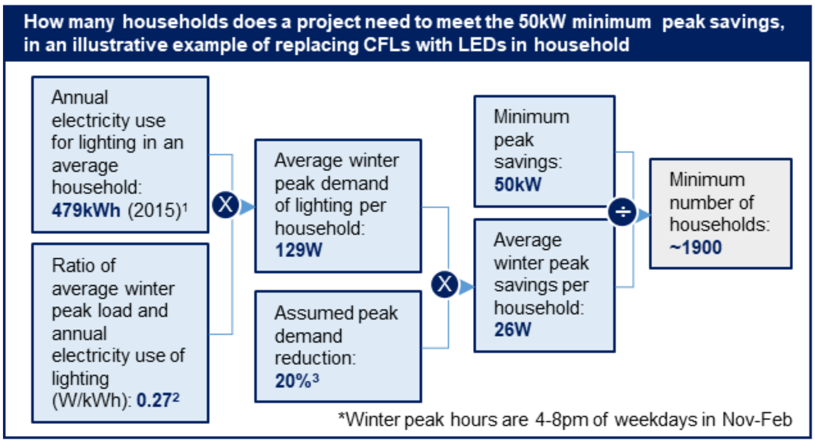
> *"It is the problem in National Grid during certain periods of day when there is a high demand…it isn't a problem for my organisation particularly."*
>
> \- SHP [8], a housing association with 10,000-50,000 homes

Moreover, there are concerns on the scale of peak impacts some efficiency measures can deliver. In the case of insulation for electrically heated properties, even if it does reduce the electricity use for heating and thus overall demand, given the wide use of storage heaters whose load occurs outside peak periods, the impacts on system peak demand would be limited. The implication is that organisations need to consider how the focus on peak savings would influence the project business case traditionally built around total energy savings.

6.6.4. Minimum peak demand reduction

The EDR Pilot sets a minimum peak saving for projects, at 100kW for projects delivering in 2015-16 and 50kW for 2016-18 (DECC, 2014a, 2015a). As shown in Fig. 6-9, in a hypothetical case of changing all CFLs to LEDs in a household, ~1,900 households need to be targeted for lighting replacement to meet the minimum 50kW winter peak savings. For most of social landlords (Fig. 3), this means a large proportion of their stock that may be difficult to target in one project – for over 90% of them, it accounts for at least 20% of dwellings. Some anecdotal evidence suggests that it might be uncommon or even difficult for social landlords to make changes to that many properties in a project in one year: *"it is usually an estate build…it is uncommon to have over 100 properties in a project."* It is due to the labour-intensive need to engage customers and obtain consent for making changes inside their properties. The schedule of internal budgeting may make it difficult to arrange for customer engagement.

> *"We set budget annually, so we do not know what is going to be in the programme for the following year, until the winter before. It makes any tenant engagement we plan quite difficult to do because we do not know what estate it is going to be done."*
>
> \- SHP [11], a housing association with 1,000-5,000 homes



1 BEIS (2016b); 2 Assumed ratio based on benchmark with British Columbia that has similar geographical characteristics with the UK as summarised in Liu (2015); 3 Assumed switch from CFL (rating 12W) to LED (rating 10W)

Fig. 6-10. Number of households needed to meet minimum savings requirements: a 'back-of-envelope' calculation

Source: BEIS (2016b); Palmer et al. (2013a); Own calculation

For communal lighting, the Energy Saving Trust conducted a trial for replacing it with LEDs in two phases over 2008-10 in 35 social housing sites of flats (EST, 2011). Given that these lightings are on 24/7, only one site of these 35 sites deliver at least 50kW of peak demand, with the rest achieving 1-42kW of reduction. Even to achieve this project size, upfront cost could be a constraint, at least then – 70-80% of LED fitting costs were covered by the trial but afterwards only a few social landlords carried out further LED installations, citing the cost as one barrier.

6.6.5. Demonstrating peak demand savings

In return for the EDR funding, organisations need to demonstrate the average load reduction of any project over winter peak hours would be at least the committed amount. This obligation is seen by many interviewees as challenging. There are three aspects. First, except for lighting in the communal area that is on 24/7, social landlords do not have any control of how electricity is used inside tenants' properties (e.g. when and how much). Given that, there is a risk that projects may not deliver the committed peak savings, thus causing financial penalties.

> *"It is a few things around control, depending on how the tenants want to use the equipment. For us, there is a risk that they do not necessarily do what we said they would do."*
>
> - SHP [4], a housing association with 1,000-5,000 homes

Second, for general needs properties, social landlords do not have access to granular metering data of tenants to allow them to estimate the baseline peak demand and the load after interventions. Tenants would choose their own energy supplier that maintains data about their energy use. Based on previous experience, it is arduous to collect that information from tenants. One respondent mentioned a project of switching to gas heating where they need to estimate savings by comparing tenants' energy bills before and after the installation. However, they had been only able to obtain pre-installation energy bills from 20% of participating households. Moreover, before the smart metering is widely installed, energy use has been recorded in cumulative terms, thus making it difficult to establish the real-time electricity load in properties. Some organisations have engaged in pilots that involve real-time metering of electricity use in social housing properties – this can provide rich data for understanding the energy use patterns and helping with measurement and verification, but such activities seem to be limited to larger, better-resourced organisations. In fact, there is concern that potential payment may not cover metering costs.

Third, while it is not uncommon to evaluate projects in social housing (Fig. 6-10), none of interviewees mentioned that peak saving is among the parameters of evaluation – common parameters include energy savings and reduction in energy expenditure. Moreover, it is felt that savings in energy, costs or even peak demand cannot reflect all the social benefits, particularly the increased comfort in under-heated properties.

> *"Not in terms of demand reduction. We are looking at how we can reduce our energy usage in our own office building or communal area. Not specifically with demand reduction."*
>
> - SHP [12], a housing association with 10,000-50,000 homes

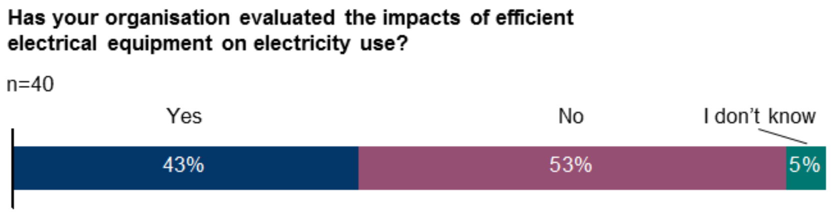


Fig. 6-11. Outcome evaluation of projects for reducing electricity demand

Source: Own survey

6.7. Discussion

6.7.1. Capacity market for promoting electricity use reduction in residential sector

Opportunities exist for reducing electricity use in households in areas like lighting, appliances and heating and insulation. However, this paper finds barriers for social landlords to utilise the EDR and capture these opportunities. Extrapolated to the whole residential sector, this paper suggests difficulty of relying on the forward capacity market as a primary vehicle for promoting electricity use reduction in households. This relates to three general characteristics of a forward capacity market.

First, the focus on peak savings does not create strong financial incentives. For electrically heated properties, although heating-related electricity use is significant, most of them use storage heaters that typically run in off-peak hours. There is little scope for peak load reduction, through efficient heating or insulation – in fact, if replaced with heat pumps, peak demand may go up given its continuous usage as recommended for efficiency reasons (e.g. Caird et al., 2012). Projects addressing 'under-heating' in households could be disadvantaged since their social benefits do not well translate into peak saving. So, it is a misalignment between the value for electricity system and that for individual households. For non-heating-related end-use, even if its peak demand coincides with system winter peak – for instance, lighting as shown in Palmer et al. (2013a) – the capacity value in the current market is a small part of benefits of energy efficiency (Liu, 2017). So, it is difficult to build a business case for efficiency improvement simply on the capacity payment, while this is the intention of EDR where eligibility is limited to projects not receiving other government funding and those with over two years of payback (DECC, 2014a).

Second, the peak-saving obligation and M&V is a challenge to target opportunities *within* dwellings. Given the practical challenge of individual households to participate in the capacity auction, it is necessary to 'aggregate' highly distributed electricity use reduction. However, organisations that could play the role (e.g. social or private landlords) often lack direct control for electricity use *within* residential homes. This means limited influence over choice and/or use of in-dwelling lighting and appliances, even when landlords provide such equipment (e.g. sheltered social housing). In the context of a capacity obligation that requires bidders to honour committed savings, it implies financial risks for under-delivery.

The EDR M&V requires direct metering or estimate based on stipulated factors. Even for the latter, evidence about how customers use electrical equipment (e.g. when it is used) is needed. For households, before smart meters are installed, it is costly and practically difficult to monitor *specific* properties that are affected by a prospective project. The challenge is reflected by many energy efficiency programmes using *ex ante* approaches for evaluating energy savings of efficiency measures, due to high transaction costs in the residential sector (CPUC, 2006; Wade and Eyre, 2015b).

Moreover, it is most likely that 'aggregators' cover some upfront costs for installation. Without the responsibility for *in-dwelling* energy bills, payback may well be too weak to justify the upfront investment, let alone the transaction costs in dealing with individual households, unless there is other funding (i.e. split incentive). Thus, if a business case exists, it is realistic of 'aggregators' targeting electricity demand reduction in *communal* areas (e.g. lighting) where they can earn some return. But this presents only a small part of opportunities. For example, in England in 2014-15, only 20% of residential dwellings are flats where there is typically communal area, while most of them (~74%) were in social and private renting (DCLG, 2016c).

Third, even for communal electricity use, participation in the EDR and capacity market requires a large project and strong financial resources of 'aggregators'. The minimum project savings are reduced from 100kW to 50kW. However, for social housing, it still could be challenging to have resources to fund project of that size (Section 5.4), even if equipment (e.g. lighting) could be replaced before full depreciation. Moreover, the capacity payment is made only after M&V – at least 6 months for the EDR or 3-4 years for the main annual capacity auctions. This may raise 'cash-flow' issues, especially for organisations with a limited budget. Even for large social landlords, besides the limited internal resources for them to develop knowledge of the EDR or projects, these are already challenges, which tend to become greater for private renting. In fact, the private renting market may be more fragmented than social housing, suggesting a lower chance of private landlords with adequate resources for 'aggregation' – for example, the Private Landlords Survey 2010 shows that organisational private landlords only account for 29% of private-rented properties in England, with over 90% of them having fewer than 25 properties in their portfolios (DCLG, 2011).

These insights about the forward capacity market are also supported by international evidence. In the U.S., ISO New England (ISO-NE) and PJM have multiple years of experience in integrating electric use reduction in their capacity markets. ISO-NE sees a higher level of its contribution to capacity adequacy – most of it comes from utility EE obligation programme and there is evidence suggesting that residential electric EE (e.g. lighting) forms part of the portfolio being offered as a capacity resource (Liu, 2017; Jenkins et al., 2011). The small contribution capacity payment makes to the overall programme expenses, i.e. 3-12% during 2011-14 (Liu, 2017), is consistent with the above argument that it does not create a strong enough incentive. Moreover, utility EE obligation programme has advantages for offering in the capacity market, including a strong funding position (e.g. from energy bill levies), internal resources (e.g. planning and development), and a large scale that justifies extensive M&V studies to support its savings claim and a 'portfolio approach' for managing the risk of capacity obligation performance (Jenkins et al., 2011). By contrast, if without these conditions, it would be challenging to develop and bid individual projects in the residential sector.

6.7.2. Additional policy provisions in the UK

The transition from CERT to ECO had 'chilling' effects on residential energy efficiency in the UK. While focusing on gas-heated households, supplier obligation programmes cover electrically heated properties. In CERT, only 3% of the households being supported rely on electric heating (DECC, 2014c). For ECO, for January 2013-September 2016, 6% of installed measures are in households using electricity as the main fuel (BEIS, 2017b). From April 2015, ECO strengthened incentive for suppliers to target properties with non-gas heating homes[69] but the share of installed measures in electrically heated homes during April 2015-September 2016 is only 5%. While this is largely in line with the share of electrically heated properties, the speed of measure installation has dramatically slowed down – while the average annual rate of SWI installation increased from 12,625 for CERT (2008-12) to 35,149 for ECO (2013-November 2016), it fails to offset the drop in that for CWI from 550,472 per year to 183,075 (BEIS, 2017b; Ofgem, 2013b). Moreover, alongside ECO, the Green Deal was set up to provide on-bill loan for efficiency measures like insulation, heating controls, efficient boilers and microgeneration. The 'Golden Rule' that cost savings should be higher than loan repayments means a focus on most cost-effective measures such as CWI (Rosenow and Eyre, 2013). This, with an unattractive interest rate and implementation issues, led to a failure in promoting efficiency measures – over

---

[69] Includes incentive uplift for insulation in non-gas heating properties and new incentive for replacing less efficient storage heaters with more efficient versions

2013-November 2016, only 5,279 measures were installed on average annually – and ultimately a termination of funding to the Green Deal in 2015 (Rosenow and Eyre, 2016).

Ample evidence exists that market transformation initiatives, including product standards, subsidies, information and marketing are key to creating the market 'pull' for efficient products (e.g. Boardman, 2004a; Boardman, 2004b; Martinot and Borg, 1998; Schiellerup, 2002). They are particularly important for products that individual households make decisions for purchasing and using, like appliance and in-dwelling lighting (Kelly, 2012). Consistent with Gaspar and Antunes (2011), one barrier highlighted in this study is high upfront cost (e.g. for LEDs). In CERT, lighting and appliances contributed ~26% of total carbon savings energy supplier subsidies to retailers greatly contributed to the uptake of efficient light bulbs and appliances (Ofgem, 2013b; Rosenow and Eyre, 2013). However, ECO phased out the support for lighting and appliance. As noted in Rosenow and Eyre (2015), this reflects the consideration to avoid the practice of energy suppliers to mail out mass-market low-cost lighting bulbs that may never be used, for meeting the saving targets. In effect, this means little direct financial incentive for buying these measures.

Given the barriers for utilising the EDR, it is not adequate to rely on a forward capacity market as a primary vehicle for incentivising electric efficiency investment in the residential sector. In other words, allowing electric efficiency projects to participate in a forward capacity market does not weaken the case for strengthening supplier obligation provisions, especially financial support, to residential efficiency measures.

Social landlords or others developing or maintaining properties may have a push in the design and equipment specification but it may well cover a subset of opportunities. Even so, for electricity use in communal areas (e.g. lighting), schemes providing financing or support with the upfront investment would be helpful, given the likely limited budget of landlords in this area. The design of scheme should accommodate the practice of replacement based on depreciation and resultant small project size. For projects of scale (e.g. affecting a large estate), innovative financing solutions like ‘leasing’ model using third-party funding may be explored.

Respondents also noted that third parties like equipment suppliers, energy brokers and ESCos have a key role in supporting social landlords, for identifying opportunities, designing and financing projects, and accessing technical expertise, as seen in Reeves (2011). Small associations may even rely on them for technology choice, project proposal and appraisal, and funding information, due to limited internal capability or expertise. Therefore, it is important that they are adequately qualified and incentivised to be ‘catalyst’ for projects that can cut electricity demand.

Finally, besides changes to equipment or physical aspect of properties, initiatives facilitating change in behaviour (e.g. energy feedback and advice) are equally important (Darby, 2010a; Elsharkawy and Rutherford, 2015; Steg, 2008). In social housing, interviewees mentioned a range of actions to raise tenants’ awareness of energy efficiency and the potential impacts on energy bills. Examples include energy advisor programmes to provide advice on use of heating systems, particularly after insulation, educational campaigns, and provision of energy cost information of properties to tenants to start a discussion about opportunities for efficiency upgrade. Smart metering and feedback it gives has the potential for promoting the uptake of efficient products and energy conservation in households (Darby, 2010b; Darby et al., 2015). There is also emerging evidence in the U.S. that behavioural initiatives can deliver notable peak savings (e.g. Opower, 2015; Walton, 2014; Thayer et al., 2016). As noted by interviewees, more research needs to be done on the implications of smart meter roll-out for tenant engagement and behaviour change in social housing, as well as the ‘best-practices’ for such initiatives that achieve above-average impacts.

6.8. Conclusion and policy implications

The residential sector is key for the electricity demand in many developed economies. In the UK, reducing electricity use in households is valuable for carbon mitigation and capacity adequacy, and helps address fuel poverty. This paper explores the potential of using a forward capacity market as a primary policy vehicle for promoting electricity use reduction in residential sector.

Using a case study of social housing, it identifies several barriers faced by residential sector to take up the funding from the forward capacity market, via the Electricity Demand Reduction Pilot. Although opportunities exist for electricity use reduction in lighting, appliances, heating and insulation, the financial incentive based on project impact on system peak demand is unlikely to be attractive and disadvantages insulation or more efficient heating system. Limited budget for electric efficiency project and inflexible requirement of over two-year payback of EDR Pilot poses the challenge of funding projects, especially for small organisations, even if they can deliver capacity value to the electricity system. Obligation to deliver committed peak savings and undertake M&V, and limited scope for payback present practical challenges and risks for developing projects to target opportunities *within* individual households. Even for electricity use in communal areas, minimum peak savings, cash-flow issues and often-limited internal resources lead to challenges of developing a project to offer into the forward capacity market.

In relation to the organisational aspects of the barriers for electric efficiency investment, the EDR modelled on the forward capacity market, and its savings-based approach, does not appear to alleviate the barriers faced by social landlords, particularly small ones. In fact, it heightens the complexity of accessing funding and the need for dedicated resources that may be lacking for many organisations (e.g. knowledge of application, available staff time, data needs for M&V, expertise for dealing with the performance and financial risks). Moreover, in the case of social housing in the UK, reducing the system peak demand does not well align with the priority in ensuring affordability and promoting tenant benefits, although this may change in the future with the development of such tariffs and rollout of smart metering. This is another organisational factor that discourages social housing providers from developing resources to support any prospective application. This underscores the need of an alternative way of providing financial incentives, which reduces the ‘hassle factor’ for organisations to undertake changes for electricity use reduction.

Therefore, a forward capacity market is unlikely to make a difference, as a primary policy vehicle, in pushing for the electricity use reduction in the residential sector. In the UK, alternative policy provisions are indispensable. For electrically heated properties, supplier obligation that focuses on insulation should be strengthened, despite the trend of it going the other way. Market transformation (e.g. product standards, financial incentive at retail and marketing) is essential, particularly for in-dwelling lighting, appliances or other equipment for which households purchase and use. Financing or funding schemes should be helpful to support upfront investment for projects affecting communal electricity use. Supply chain and behaviour change are also important levers for reducing residential electricity use.

Annex 1 | Sample topic guide for semi-structured interviews

Previous projects

- Characteristics of previous projects
- Motivations for undertaking these projects
- Electric efficiency measures: untapped potential and barriers for identifying opportunity
- How important electric energy efficiency is to your organisation
- Major funding sources
- Evaluation of their impacts on electricity use
- Indicators used (e.g. energy use, peak demand and carbon emissions)
- Motivation and experience

Planned projects

- Measures being considered and how many property units to target
- Any potential funding sources being considered

EDR Pilot and alternative policy

- Engagement with the EDR Pilot
- Awareness of the EDR pilot
- If participated, project characteristics (e.g. measures, size of peak demand, project model – e.g. third-party)
- Outcomes and why
- What do you think about the design of EDR Pilot?
- Design you would like to see changed
- Overall energy savings vs. peak savings
- What project model would you prefer (e.g. third-party company giving proposition and sharing risk)
- What are the key characteristics of a funding programme that would interest your organisation? (e.g. barriers it should target, how financial incentive is given, M&V requirements)

Annex 2 | Anonymised list of interviewees

Interviewee code	Type of organisation	Size of dwellings stock
SHP 1	Housing Association	10,000-50,000
SHP 2	Housing Association	5,000-10,000
SHP 3	Housing Association	1,000-5,000
SHP 4	Housing Association	1,000-5,000
SHP 5	Housing Association	5,000-10,000
SHP 6	Housing Association	1,000-5,000
SHP 7	Housing Association	5,000-10,000
SHP 8	Housing Association	10,000-50,000
SHP 9	Housing Association	10,000-50,000
SHP 10	Local Authority	5,000-10,000
SHP 11	Housing Association	1,000-5,000
SHP 12	Housing Association	10,000-50,000
SHP 13	Local Authority	10,000-50,000
SHP 14	Housing Association	1,000-5,000
SHP 15	Housing Association	<1,000
SHP 16	Housing Association	10,000-50,000
SHP 17	Housing Association	1,000-5,000

SHP 18	Housing Association	1,000-5,000
SHP 19	Local Authority	5,000-10,000
SHP 20	Housing Association	10,000-50,000
SHP 21	Housing Association	1,000-5,000
SHP 22	Housing Association	5,000-10,000
SHP 23	Local Authority	1,000-5,000
SHP 24	Housing Association	<1,000

7 | Paper 4: Demand response and energy efficiency in the capacity resource procurement: case studies of forward capacity markets in ISO New England, PJM and Great Britain

This paper takes a break from the first research question of 'whether the forward capacity market can be a primary policy vehicle to give incentives and drive investment in electric EE', to the second question of 'whether a forward capacity market, as a mechanism to ensure capacity adequacy, can promote electricity use reduction as a capacity resource'.

7.1. Abstract

Demand-side resources like demand response (DR) and energy efficiency (EE) can contribute to the capacity adequacy underpinning power system reliability. Forward capacity markets are established in many liberalised markets to procure capacity, with a strong interest in procuring DR and EE. With case studies of ISO New England, PJM and Great Britain, this paper examines the process and trends of procuring DR and EE in forward capacity markets, and the design for integration mechanisms. It finds that the contribution of DR and EE varies wildly across these three capacity markets, due to a set of factors regarding mechanism design, market conditions and regulatory provisions, and the offering of EE is more heavily influenced by regulatory utility EE obligation. DR and EE are complementary in targeting end-uses and customers for capacity resources, thus highlighting the value of procuring them both. System needs and resources' market potential need to be considered in defining capacity products. Over the long-term, it is important to ensure the removal of barriers for these demand-side resources and the capability of providers in addressing risks of unstable funding and forward planning. For the EDR Pilot in the UK, better coordination with forward capacity auction needs to be achieved.

Key Words: demand response, energy efficiency, capacity market

7.2. Introduction

Emerging agenda of capacity adequacy, renewable energy integration and economic efficiency has fuelled the interest in demand response (DR) and energy efficiency (EE) for supporting the operation of electrical system. There is extensive literature showing that DR and EE can be reliable, cost-effective alternative to generation capacity (Aunedi et al., 2013; Boardman, 2014; Bradley et al., 2013; Pudjianto et al., 2013; Strbac, 2008; York et al., 2007).

These demand-side resources can provide three types of system service. Firstly, for contributing to the capacity adequacy, DR can induce dispatchable, temporary load reduction in system peak hours and more efficient equipment installed in the EE projects can achieve non-dispatchable, permanent demand reduction (e.g. Darby and McKenna, 2012; Poudineh and Jamasb, 2014). Secondly, if dispatched more frequently and rapidly, DR can also support short-term system balancing (e.g. ancillary services like frequency response). Thirdly, in some wholesale energy markets, DR may bid as an energy resource and dispatch according to pricing signals to avoid operating costlier generation during high-demand periods. However, for now in many countries (e.g. UK and the U.S.), DR is utilised to support capacity adequacy (Liu et al., 2015).

With the electricity market unbundling, system operators become responsible for ensuring capacity adequacy. Many establish forward capacity markets to procure resources several years ahead of time. Unlike regulatory resource planning, it is a ‘market-based’ mechanism to remunerate resources for their capacity value, and to incentivise their investment. The popularity of forward capacity market is widespread as it is being created or explored in many jurisdictions in the USA, Australia and Europe (e.g. the UK, Germany and France).

There is strong policy interest in opening forward capacity market to demand-side resources. In the USA, ISO New England (ISO-NE) and PJM Interconnection (PJM) already allow DR and EE to directly compete against generation and other capacity types in their capacity markets, while DR may also offer into energy and ancillary markets (Cappers et al., 2010; Faruqui et al., 2010; Walawalkar et al., 2010; Zarnikau, 2010). In Europe, the increased need to ensure capacity adequacy and the value of engaging end-users in energy markets underpin the enthusiasm for exploring options for integrating demand-side resources (Torriti et al., 2010). For example, promoting the participation of DR is a key objective of the French capacity mechanism. In the UK, while DR already contributes to the system operation through programmes like the short-term operating reserve, the new Great Britain (GB) Capacity Market, as part of the Electricity Market Reform, provides a route for DR to realise its capacity value. It is exploring the potential of integrating EE into the GB Capacity Market as well, through the Electricity Demand Reduction (EDR) Pilot using forward auction to acquire peak savings from EE projects (DECC, 2014a).

The literature has discussed the relationship of DR and EE. King and Delurey (2005) found DR like dynamic pricing and reliability programmes had a small effect on energy saving. Darby and McKenna (2012) discussed that while EE may reduce the load to provide DR, it could ‘reduce discomfort’ and increase the ‘social acceptability of load shifting’. Regarding the system operation, while smart grid applications like DR can cut peak demand, EE is vital for mitigating carbon emissions (e.g. Vidalenc and Meunier, 2011), and EE may lead to more volatility in load curve, which suggests greater need for options like DR to help integrate renewables (Boßmann et al., 2013). Nonetheless, there is limited literature on the nature, scale and driving forces of the participation of DR and EE in forward capacity markets, particularly how these demand-side resources may differ in such aspects. Empirical understanding of these relationships is key to the design of mechanisms for integrating DR and EE into the capacity market, and assessment of their potential scale of participation and whether other supportive policies would be necessary.

This paper focuses on DR and EE as capacity resources. It aims to fill the gap by examining 1) the process and outcomes of procuring DR and EE in forward capacity markets, and 2) policy implications for the design of procurement mechanisms. It focuses on case studies of ISO New England (ISO-NE), PJM and GB capacity markets to derive lessons widely applicable to other regions working to integrate DR and EE in their capacity mechanism or resource planning (e.g. China). After briefly introducing the methodology (Section 7.3), this paper reviews the procurement mechanisms for DR and EE in forward capacity markets. Section 7.5 presents and discusses the patterns of DR and EE participation in forward capacity auctions. Section 7.6 discusses the policy implications for designing procurement mechanisms and Section 7.7 concludes.

7.3. Methodology

This study focuses on the forward capacity markets of ISO-NE, PJM and GB to reflect the diversity of regulatory and policy background, market development and operational characteristics of electricity system (Table 7-1). ISO-NE and PJM have a long history of procuring DR and EE in forward capacity markets, which is useful for understanding the potential of integration and how it evolves with system needs and regulatory and market conditions. This study also includes the GB Capacity Market, which has a different set-up for procuring DR and EE and a unique policy objective, to discuss what design of integration mechanism would be more appropriate.

Table 7-1. Key characteristics of forward capacity markets in ISO-NE, PJM and GB

	ISO-NE	PJM	GB Capacity Market
Annual Peak Demand	~28GW	~165GW	~56GW
Season of Highest Peak	Summer-peaking system	Summer-peaking system	Winter-peaking system
Geographic Coverage	Various states in Northeast of the USA	Various states in Northeast, Midwest and South of the USA	England, Wales and Scotland
Operation	2010 onward	2007 onward	2017 onward
Integration of DR	Directly compete against other resources in forward auctions from 2010.	Directly compete against other resources in forward auctions from 2007.	DR can participate in forward auctions from 2018. A dedicated auction is designed for DR and small generation for 2016-18.
Integration of EE	Directly compete against other resources in forward auctions from 2010.	Directly compete against other resources in forward auctions from 2012.	The Electricity Demand Reduction Pilot (for delivery in 2015-18) trials the feasibility of integrating EE into capacity market.
Key Features	• Long history of integrating DR and EE • EE makes meaningful contributions • DR used to make meaningful contributions but declines in recent years	• Long history of integrating DR and EE • DR makes meaningful contributions • EE participation still low • Differentiated offering and evolution of capacity products	• Limited experience of integrating DR and EE • Limited-time offering of differentiated DR product • Possible issues of integrating dedicated auctions with main forward capacity auctions
Main Issues Facing Policy Makers	Under-performance of generation capacity led to change in incentive structure	Under-performance of capacity and changing system needs led to ‘restructuring’ of product definition	Promoting the participation of DR and EE, and using capacity market to incentivise EE investment

In order to analyse the participation trends of DR and EE, this study uses historical results of the main forward capacity auctions in ISO-NE, PJM and GB as well as the outcomes for dedicated auctions for DR and EE in GB. Market activity reports of PJM are used to analyse the pattern of DR and EE in taking on capacity obligations and targeting end-uses and customer segments for capacity resources. To understand the relationship between regulatory EE obligations for utilities and the contribution of EE in capacity auctions, impacts of utility programmes are collected from the publications of regulators and the American Council for an Energy-Efficient Economy, and the database of Northeast Energy Efficiency Partnership. This study also reviews the rules of participation and performance measurement and verification (M&V).

7.4. Mechanisms for procuring DR and EE

Forward capacity markets procures resources several years (e.g. three or four) beforehand to meet the capacity requirement determined based on peak demand forecast and reserve margin (Bowring, 2013a). This is done through auctions where eligible resources are selected based on the ‘merit order’ of their bid price, until the capacity requirement is met. Resources clearing the auction receive payment during the relevant year for the obligation to deliver a specific amount of capacity, and are subject to penalty if they under-deliver (Benedettini, 2013).

DR and EE may directly compete against other resources in the capacity auction or be procured via dedicated auctions. Three key barriers exist for integrating DR and EE into forward capacity markets: 1) capacity product definition; 2) treatment of demand-side resource; and 3) M&V. Appropriate regulatory provisions are necessary for ensuring viable routes to market for DR and EE.

7.4.1. Evolution of capacity products

Capacity product definition specifies the parameters of capacity obligation and is the pre-condition for resources to be ‘tradable’. For demand-side resources, it stipulates the dispatch requirement for DR and the determination of capacity value for EE. As shown in Table 7-2, different capacity products are available for DR and EE in the ISO-NE, PJM and GB capacity markets.

Table 7-2. Definition of DR and EE capacity products in ISO-NE, PJM and GB Capacity Market

	Availability	Requirements of capacity performance
ISO-NE		
Real-Time DR	2010 onward	Dispatchable as requested all year round
Real-Time Emergency Generation	2010 onward	Dispatchable as requested in 7am-7pm of working days
On-Peak EE	2010 onward	Average demand reduction of 1pm-5pm of working days in June-August and 5pm-7pm of working days in December-January
Seasonal Peak EE	2010 onward	Average demand reduction over hours during working days in June-August and December-January when the real-time hourly system load is equal to or greater than 90% of the most recent '50/50' system peak load forecast[1] for the applicable season
PJM		
Limited DR	2007-18	Dispatchable in 12pm-8pm of working days in June-September, for up to 10 calls that last for up to 6 hours
Extended Summer DR	2014-18	Dispatchable in 10am-10pm of working days in June-October and May the following year, with no limit on number of calls that last for up to 10 hours
Annual DR	2014-18	Dispatchable in 10am-10pm of working days in June-October and May the following year and 6am-9pm of working days in November-April, with no limit on number of calls that last for up to 10 hours
Capacity Performance DR	2018 onward	Dispatchable in 10am-10pm of working days in June-October and May the following year and 6am-9pm of working days in November-April, with no limit on number or duration of calls
Basic Capacity DR	2018-20	Dispatchable in 10am-10pm of working days in June-September, with no limit on number of calls that last for up to 10 hours
Capacity Performance EE	2018 onward	Lower of average demand reduction of 3pm-8pm of working days in June-August, and 8am-9am and 7pm-8pm of working days in January-February
Basic Capacity EE	2012-20	Average demand reduction of 3pm-8pm of working days in June-August
GB Capacity Market		
Demand-Side Response (DSR)	2017 onward	Dispatchable as requested all year round
Transitional Arrangements	2016-18	Dispatchable in 9am-11am and 4pm-8pm of working days in October-April, with no limit on number or duration of calls
EDR Pilot – EE	2015-18	Average demand reduction of 4pm-8pm of working days in November-February

[1] Load forecast is based on probability. A '50/50' load forecast means that there is a 50% chance for the actual load to exceed the forecast.

a) ISO-NE

DR and EE are eligible in the Forward Capacity Market since 2010. For DR, temporary shifting or curtailment of demand at a customer's site can qualify as Real-Time DR, with behind-meter generation participating as the Real-Time Emergency Generation[70]. Once dispatched, DR

---

[70] Subject to environmental permits. Its operation is limited to emergency periods as called by the system operator. Moreover, compensation in the FCM for RTEG is limited to 600MW, with the amount above it subject to price proration.

should respond within 30 minutes. Although there is no ceiling on the dispatch frequency and duration, the actual dispatch is limited in number in the past years (e.g. Hurley et al., 2013). For example, during 2013-14, Real-Time DR was dispatched for only 7 hours in summer and around 3 hours in winter (Smith, 2013, 2014). EE can offer as either an On Peak or a Seasonal Peak resource. The On Peak EE product is designed for measures able to demonstrate peak savings in the pre-defined peak hours, whereas Seasonal EE is for those whose operation is weather-sensitive.

Recent underperformance of generation (e.g. winter and summer of 2013) led ISO-NE to change the incentive structure for all resources in the Forward Capacity Market (Hogan et al., 2015). The pay-for-performance design, which is effective from 2018-19, introduces a dual-settlement process whereby resources first take on capacity obligations and are subsequently subject to a settlement for any deviation from obligation. Resources that over-deliver are paid at an administratively set rate for the incremental delivery, and under-performing ones have to pay other to ‘buy out’ their positions (ISO-NE, 2015a). The penalty regime for under-delivery is also strengthened.

b) PJM

The Reliability Pricing Model, or PJM’s forward capacity market, began operation in 2007. For 2007-12, there were two routes for DR: 1) Emergency DR in the main three-year-forward auctions and 2) Interruptible Load for Reliability (ILR) offering outside the forward auctions close to delivery years and consist of legacy DR programmes before the Reliability Pricing Model. Initially, PJM had set aside some forward procurement targets for ILR, given the claimed difficulty in making three-year forward commitment (Bowring, 2013a). With ILR growing from below 2GW in 2007-08 to almost 9GW in 2011-12, however, concerns emerged about its impact on the integrity of forward capacity auctions (Hurley et al., 2013). Therefore, PJM ended ILR and from 2012-13 all DR is required to offer into the forward auctions.

The capacity products for DR and EE have considerably evolved since then. For 2012-14, DR had limited dispatchability, being required to deliver only during 12pm-8pm of working days between June and September for a maximum duration and number of times in a year. Concerned with the growing reliance on such DR, PJM introduced Extended Summer DR and Annual DR of higher dispatchability requirements, while the existing DR was re-classified as Limited DR (Glazer, 2014). As for EE, PJM first allowed its participation in 2012-13 and required it to demonstrate capacity performance based on the average demand reduction over pre-defined peak hours in summer.

PJM 'restructured' the capacity products from 2018-19. It retired three DR products and introduced two products – Capacity Performance and Base Capacity – for all resource types, with the intention of acquiring Capacity Performance products only from 2020-21. This change aims to strengthen capacity reliability during winter as well as summer peaks (PJM, 2015a). It is in response to the weakness of generation performance in January 2014 when prolonged cold weather led to a 25% higher peak demand and striking unavailability of generation due to constraints in fuel supply and mechanical operation (PJM, 2015c). For example, on 7 January 2014, 22% of total capacity experienced forced outage – above three times the historical average of 7% – and 85% of the forced outage came from generation (PJM, 2014c). While Annual DR is introduced from 2014-15, most of the DR is only required to deliver in summer, making it difficult to rely on DR in winter.

The product 'restructuring' sets higher performance requirements (Table 2). For DR, the Capacity Performance is an 'upgraded' version of Annual DR in that the maximum duration of response is removed, whereas the Base Capacity product is similar to Extended Summer DR on the frequency and duration in response. For EE, while the Base Capacity is equivalent to the existing EE product, capacity value of the Capacity Performance is the lower of average peak savings over performance hours of winter and summer.

Recognising products' different 'reliability' value, PJM sets procurement constraints for specific products and allows differentiated financial compensation. For 2014-17, minimum targets are set for procuring Annual Resources (i.e. Annual DR, EE and generation) and Extended Summer DR, whereas for 2017-18 maximum limits are established for Limited and Extended Summer DR. For 2018-20, maximum limits are placed on Base Capacity products of DR and EE, while Base Capacity products of all resources should not exceed 20% of total procurement (PJM, 2015c). To fulfil these constraints, forward auctions can select resources out of 'merit-order' and if this occurs, resources of greater 'reliability' value may receive higher capacity prices. For example, in the main forward auctions for 2014-18, Annual and Extended Summer resources cleared at a price 0-20% higher than Limited resources, although the difference can get bigger depending on the resource portfolio and bid prices (PJM, 2011, 2012, 2013, 2014a).

c) GB Capacity Market

The GB Capacity Market forms a part of the Electricity Market Reform in the UK. It runs four-year forward auctions, complemented with year-ahead auctions for 'fine-tuning'. Its first delivery is 2017-18, with the current design (i.e. 'load-following') obliging resources to deliver when system stress event occurs (DECC, 2016b). For giving targeted support to the DR, 'transitional arrangements' use year-ahead auction to procure broad DR resources (e.g. 'turn-down' DR involving changes in electricity-using behaviours, and small generation) for 2016-17, and only 'turn-down' DR for 2017-18. Different from the 'load-following' obligation, the 'transitional arrangements' offer time banded product required to deliver only during 9am-11am and 4pm-8pm of working days in October-April.

While EE is not yet eligible in the GB Capacity Market, the Electricity Demand Reduction (EDR) Pilot was set up in 2014 to select electrical efficiency projects based on the 'merit order' of bid prices (DECC, 2014a). Projects need to deliver their committed average peak savings over 4pm-8pm of working days in November-February. Different from the GB Capacity Market paying resources the clearing price by delivery year, the EDR Pilot makes one-off payment based on projects' bid price.

7.4.2. Treatment of demand-side resources

Generation and demand-side resources have different operational characteristics. The extent to which rules applicable to generation would apply to demand-side resources reflects the regulatory judgment on how demand-side resources should be treated (Hurley et al., 2013). Of particular note is the debate on whether DR with the capacity obligation should be required to offer into wholesale energy markets like generation (i.e. 'must-offer' requirement). For generation, the 'must-offer' requirement aims to mitigate the risk of resources withholding to drive up energy price (FERC, 2013a). In 2013, the Federal Energy Regulatory Commission (FERC) accepted the proposal of ISO-NE to require DR to make 'cost-based' offers into the day-ahead and real-time energy markets, as a solution to address the inefficiency of dispatching resources without considering whether it is economic to do so during system emergencies (FERC, 2013b).

In 2014, the PJM market monitor filed a complaint asking to subject DR to the same 'must-offer' requirement and offer caps in energy markets as generation. However, in 2016, FERC refused the complaint, citing that insufficient justification is provided to support the identical treatment of DR regarding the 'must-offer' requirement, given the long-accepted distinction of economic DR and that for reliability (FERC, 2016). It also found that the existing offer caps already allow generation and demand-side resources to bid at marginal cost into the energy market.

7.4.3. Measurement & Verification (M&V)

DR and EE realise their capacity value by demand reduction, which is difficult to measure directly. To overcome this barrier, it is necessary to establish a baseline and determine the load reduction DR and EE achieve from there. For DR, it involves estimating the difference of real-time load during a DR event and the ‘counter-factual’ baseline established from loads in recent similar days and right before the DR event (PJM, 2015b).

For EE, the baseline is usually the average load of electrical equipment being replaced or meeting efficiency standard during system peak. To estimate the capacity value, the International Performance M&V Protocols are followed in ISO-NE, PJM and the EDR Pilot (ISO-NE, 2014b; PJM, 2010). While long-term monitoring or simulation may be needed for equipment of variable operation, it is possible to use stipulated factors and algorithms from load research (PJM, 2010). Of states in ISO-NE and PJM, there are efforts to update these factors and algorithms regularly to reflect the average load pattern. In ISO-NE, it is even required that research supporting stipulated algorithms and factors should not be older than five years when the M&V plan is submitted (ISO-NE, 2014b). For the EDR Pilot, it is the responsibility of project sponsor to provide evidence for the load pattern of electrical equipment.

As EE can achieve permanent peak savings, there are three implications. Firstly, for peak demand forecast, it is key to account for the peak impacts of EE to avoid excessive capacity procurement. In so doing, however, only those EE resources not offering in capacity auctions (e.g. due to higher efficiency standards or market rules) should be covered (Peterson et al., 2006; PJM, 2015c). Secondly, the M&V should accommodate the possibility that the same electricity end-use provides both DR and EE capacity (e.g. air conditioning). It is reasonable to estimate the capacity value of EE measures before that of DR, while real-time loads of recent similar days before the DR event should already reflect the peak impacts of EE measures. Thirdly, over the lifetime of EE measures, their capacity value may change because of operational and other factors (e.g. rebound effect). Therefore, it is important that capacity value reflect the latest operational status, for peak forecast or existing EE to continue offering into capacity auctions, particularly if there is a significant contribution from EE resources. For each delivery year, ISO-NE and PJM require resource providers to submit updated M&V plan to report changes in peak saving (e.g. due to retirement of EE measures or changes in baseline).

7.5. Characteristics of DR and EE participation

7.5.1. *Overall trend in main capacity auctions*

a) ISO-NE

DR led the participation of demand-side resources in early years but in recent forward auctions, its contribution declined sharply (Fig. 7-1). After total DR capacity increased by 26% between 2010-11 and 2015-16 to reach 1,985MW, it then began to decline – for 2016-17 and 2018-19, cleared DR in the main forward auction was only 56% and 33% of that for 2015-16 respectively. Therefore, the share of DR in total capacity procurement drops from 4-5% before 2015-16 to about 1% in 2019-20.

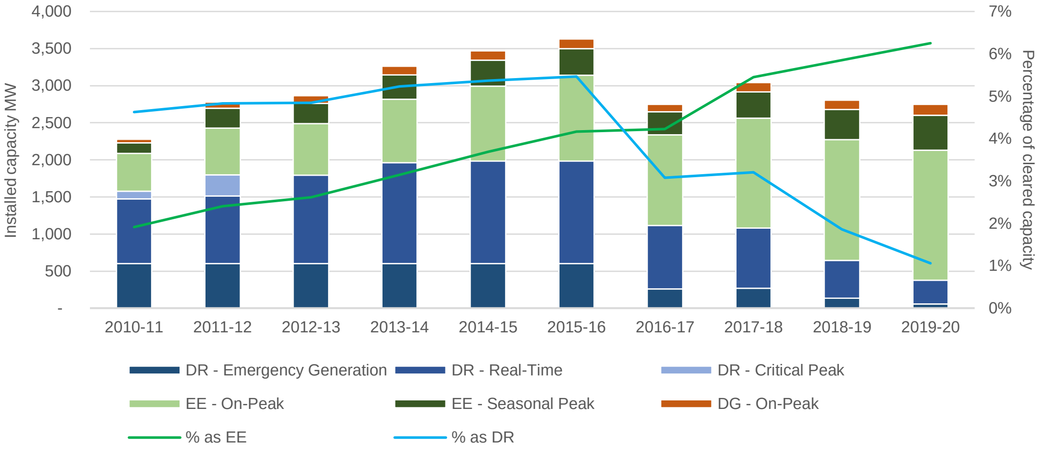


Fig. 7-1. DR and EE resources clearing in the Forward Capacity Auctions of ISO-NE Forward Capacity Market (FCM)

Source: ISO-NE Forward Capacity Auctions Results

Changes in market design can explain the downward trend. From the auction for 2016-17, a number of market rules are revised such as the requirement of DR to offer into energy market and report near-real-time performance data to ISO-NE, and the removal of auction floor price (FERC, 2013b; Price, 2013). Difficulty in fulfilling these requirements (e.g. offering into energy markets on an hourly basis) and less certainty over capacity price undermine the economic case for DR contracts (RTO Insider, 2013). Consequently, for 2016-17, DR providers 'de-listed' nearly 40% of the existing capacity, with major participants retreating from the capacity market (Platts, 2013). Coupled with the 'risk of significant penalties' under the Pay-for-Performance design, the downward trend of cleared DR continued in 2017-20, despite capacity prices notably higher than previous auctions (Katsigiannakis et al., 2016).

By contrast, EE plays a bigger role. From 2010-11 to 2019-20, cleared EE more than tripled to 2,224MW, with its share in the total cleared capacity rising from 2% to 6%. Two factors can explain this upward trend. Firstly, the utilities obliged to undertake EE programmes lead in offering EE capacity and their activities of acquiring EE have accelerated. For 2012-20, utilities and 'quasi-government' entities (e.g. Efficiency Maine and Efficiency Vermont) with the regulatory obligation to undertake EE projects have contributed over 94% of total EE capacity cleared in the main forward auctions, with the share rising to 99% in the auctions for 2015-19. As seen in Fig. 7-2, the growth of EE capacity is driven by states like Massachusetts and Connecticut that already make significant contributions. This trend correlates with the scale and trend of peak savings achieved or planned for these two states, while all six states covered by ISO-NE heightened their EE targets (Fig. 7-3). Secondly, there is regulatory incentive, at least in some states, for utilities to participate in capacity market to support the financial position of obliged EE programmes and reduce the customer surcharge burden for funding them. In Massachusetts, the obliged utilities seek revenues from capacity market alongside other opportunities (e.g. Regional Greenhouse Gas Initiative) to lower the Energy Efficiency Surcharge levied on customers to fill the gap between programme budget and proceeds for fixed System Benefit Charge, capacity market and other sources (MEGEEPA, 2015).

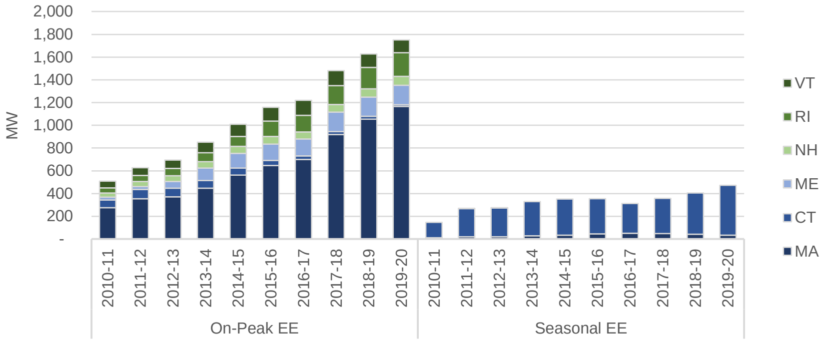


Fig. 7-2. Participation of EE capacity by state in the ISO-NE Forward Capacity Market

Source: ISO-NE Forward Capacity Auctions Results

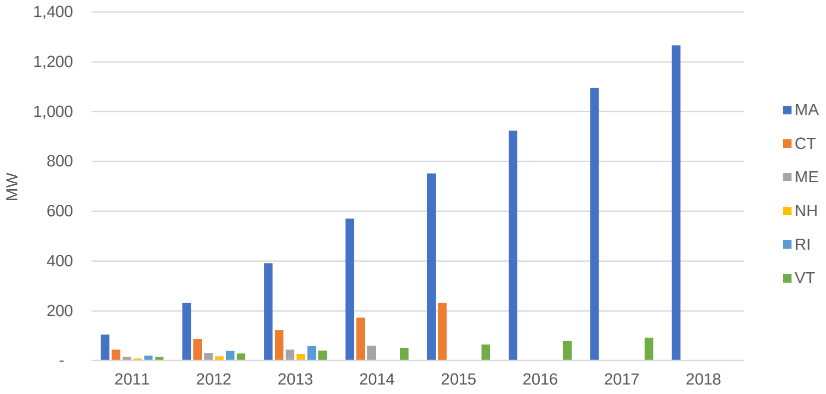


Fig. 7-3. Cumulative peak savings of utility energy efficiency programmes in ISO-NE territory from 2011

Source: Massachusetts Energy Efficiency Advisory Council; Energize Connecticut; Regional Energy Efficiency Database

b) PJM

DR is the dominant demand-side resource in the Reliability Pricing Mechanism (Fig. 7-4). For 2012-13, cleared DR was 7,047MW or 5% of the procured capacity, increasing from only 1,365MW or 1% of total capacity in the auction for 2011-12. This is due to the requirement of all DR to offer in the main three-year forward auctions (Hurley et al., 2013). Since then the DR capacity has almost doubled to account for 9% of total procurement for 2015-16, before decreasing by 19% over auctions for 2016-18. A number of factors contributed to the decline, including the tighter procurement cap for Limited DR and shorter lead-time for load response from two hours to 30 minutes. These led to a 43% drop in the DR offered into auctions from nearly 20GW in 2015-16 to 11GW in 2017-18, while the low capacity price in the 2016-17 auction also played a part. In comparison, cleared EE capacity constituted less than 1% of total capacity in past auctions, although its amount more than doubled from 569MW to 1,339MW between 2012-13 and 2017-18.

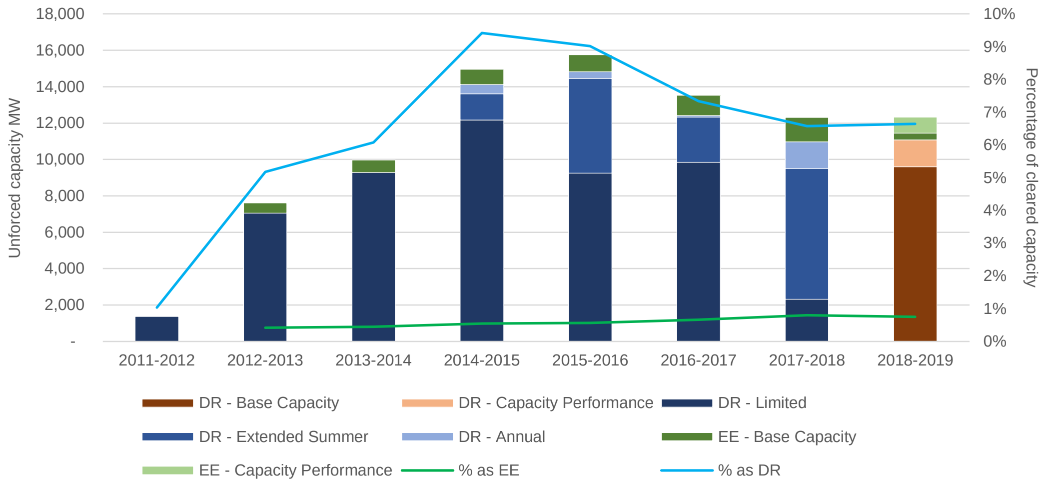


Fig. 7-4. DR and EE capacity clearing in the Base Residual Auctions of PJM Reliability Pricing Mechanism

Source: PJM RPM Base Residual Auction Results

The auction for 2018-19 is the first time that resources are re-defined into Capacity Performance and Base Capacity products. Compared with 2017-18, cleared DR and EE capacity dropped by 4% and 11% respectively[71]. This corresponds with the tightening of capacity performance for DR and a new way of determining capacity value of Capacity Performance EE product.

Of cleared DR capacity, that with limited dispatchability holds a dominant position. For 2014-17, Limited DR and Extended Summer DR contributed 62-86% and 10-35% respectively of total cleared DR capacity, whereas the share of Annual DR was only 1-4%. However, the 'make-up'

---

[71] As compared with the 2017-18 BRA, the UCAP of DR increased marginally by 1% and that of EE decreased by 7%. However, as PJM no longer discounts the UCAP of DR and EE by the DR factor of around 95% in the 2018-19 BRA, this paper undertook adjustment to see the change on the installed capacity basis.

of DR changed notably in the auction for 2017-18 where the share of Limited DR dropped to 21% and that of Extended Summer DR and Annual DR increased to 65% and 14% respectively. This is because of the maximum acquisition targets for Limited DR and Extended Summer DR that were instituted, for the first time, for 2017-18 (PJM, 2014b). For 2018-19, most of DR capacity cleared as Base Capacity product, with only 13% offering as Capacity Performance product with higher dispatchability requirement. It is consistent with previous delivery years – if compared with 2017-18, the amount of Base Capacity and Capacity Performance products, respectively, is more or less that of Extended Summer and Limited DR combined and that of Annual DR. This pattern suggests the actual or perceived barrier of customers to respond to more frequent and longer DR events, and thus the difficulty of resource developers to provide capacity that can meet the higher delivery requirements. If the Base Capacity product type is to be phased out as planned for future years, it implies challenges for resource developers to offer DR complying with high performance requirement and maintain the current level of participation. However, what and how much DR would *actually* be offered is subject to a number of technical and market factors (e.g. capability of customers, strength of market incentive and business model for DR development).

As for EE, in contrast, 71% of capacity cleared as Capacity Performance product for 2018-19. While it is still unclear whether a similar pattern is to persist into future years, this reflects the confidence of EE resources in demonstrating peak savings in both summer and winter months, without significantly compromising their capacity value. As shown in Section 4.3, this may be largely due to the dominance of lighting measures in the EE portfolio in the PJM forward capacity market, which are found by Liu (2015) to be less variable than other EE measures (e.g. air conditioning) in their peak savings between seasons.

Compared with ISO-NE, the low participation of EE in PJM can be explained by a combination of regulatory, market and design factors (Neme and Cowart, 2014). Firstly, the level of utility EE obligations tends to be smaller in states served by PJM. Between 2008 and 2014, as a percentage of retail sales, the annual incremental electricity savings of utility EE programmes were higher in states covered by ISO-NE than those of PJM (Fig. 7-5). To the extent that utility programmes are the major source of EE capacity in PJM, their relatively low targets and activities suggest a small potential to offer into capacity auctions. Secondly, even if the obliged utilities participate, they seem to have ‘under-bid’ by offering at a level significantly lower than their actual peak savings (Knight et al., 2014). Factors such as high transaction costs (e.g. for M&V) and risk of under-performance penalty may have created barriers. Although it may be justifiable to under-bid to hedge the risk of under-performance, excessive under-bidding undermines the financial return for EE and the benefits of its integration in capacity procurement. Thirdly, unlike ISO-NE where EE measures can offer as long as they are operable, PJM only allows them to participate for up to four years. It not only affects the potential amount of EE to offer for each delivery year, but also limits the timeframe over which financial payment can be obtained, thus undermining the motivation of resource providers.

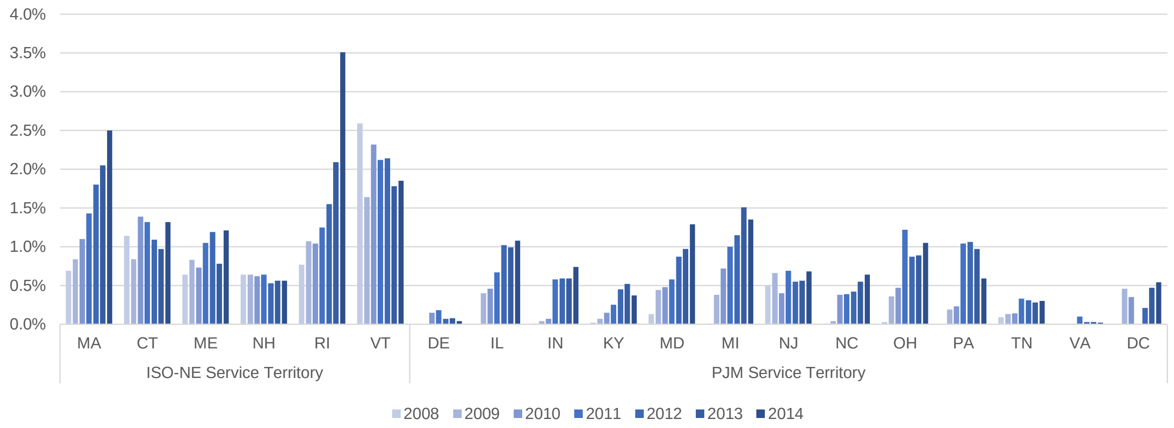
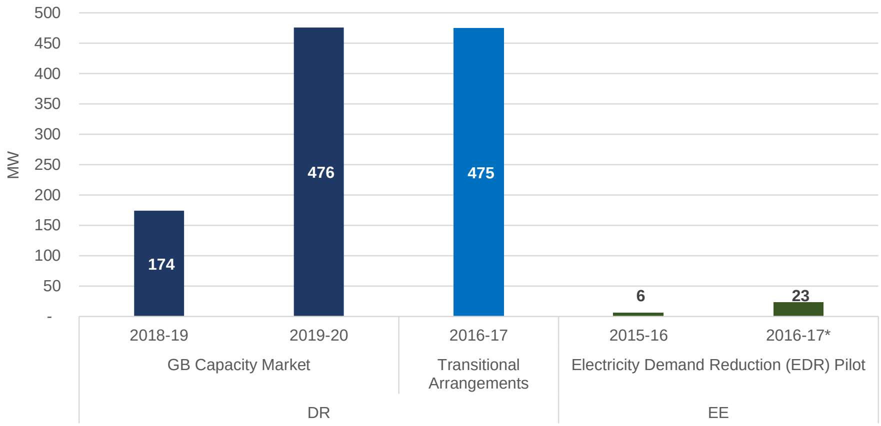


Fig. 7-5. Annual incremental net electricity savings of utility programmes as percentage of retail sales in states of ISO-NE and PJM

Source:Downs et al. (2013); Foster et al. (2012); Gilleo et al. (2014); Gilleo et al. (2015a); Molina et al. (2010); Sciortino et al. (2011)

c) GB Capacity Market

The first two four-year forward auctions of GB Capacity Market, for delivery in 2018-19 and 2019-20 respectively, have completed[72] (Fig. 7-6). Given the embryonic nature of GB Capacity Market, it is not surprising to see the cleared DR rise from 174MW for 2018-19 to 476MW for 2019-20, as resource providers become more experienced with participation. However, overall, DR makes only marginal contributions in the GB Capacity Market, with their cleared capacity being 0.4% and 1.0% of total procurement for 2018-19 and 2019-20 respectively.



[1]In the second EDR auction, resources can choose to deliver in the winter period of either 2016-17 or 2017-18.

Fig. 7-6. DR and EE capacity in the GB Capacity Market, transitional arrangements and Electricity Demand Reduction Pilot

Source: Auction results of GB Capacity Market, 'transitional arrangements' and the EDR Pilot

In the 'transitional arrangements' auction for 2016-17, DR takes up 475MW or 59.2% of the capacity obligation, while the rest is awarded to small-scale generation. It only represents around 1.0% of capacity needs in the GB system.

Given the sizable DR potential assessed in other studies (e.g. Element Energy, 2012), two reasons can help explain the small contribution of DR in the GB Capacity Market. Firstly, the

---

[72] In 2016, the government decides to bring forward the first delivery year to 2017-18 and use year-ahead auction to procure capacity for that delivery year.

dominance of existing generation capacity, especially that bidding low price to avoid closure, represses the clearing price to a level unacceptable to many DR providers. For 2018-19 and 2019-20, existing generation constitutes 57% and 82% of total capacity entering auctions respectively, whereas the share of DR is only around 1%. With these auctions clearing at £19.4/kW/year and £18/kW/year, 71% and 31% of DR capacity opts to exit the auction respectively. Secondly, since before the latest reform DR may not offer concurrently in the GB Capacity Market and 'transitional arrangements'[73], some providers may have strategically dropped out of the GB Capacity Market auctions for being able to participate in the 'transitional arrangements'. In the GB Capacity Market auction for 2018-19, apart from that 40% of qualified DR withdrew before the auction, the exit of DR capacity from auction largely occurred at between £35-40/kW/year and £25-30/kW/year, which is actually higher than the compensation level (£11-30/kW/year) in an existing DR programme, Triad Avoidance (DECC, 2015c). For 2019-20, only 676MW of DR was offered, which is a 30% drop from the 2018-19 auction. By contrast, 964MW of DR offered into the 'transitional arrangements' auction for 2016-17, with 49% of it clearing at the price of £27.5/kW/year.

The EDR Pilot has completed its two auctions for EE projects. The first auction procured 6MW of peak savings from EE for delivery in 2015-16, while 23MW cleared in the second one for delivery in either 2016-17 or 2017-18. There are three points about the EDR. Firstly, the procured EE resources make very small contributions to capacity. This may in part be due to the design of auction and market response to it. In fact, the first and second auctions managed to allocate only £1.3m and £4.7m to EE projects, although the budget for these two auctions was £10m and £6m respectively. Moreover, nearly all successful projects target lighting systems of commercial and industrial customers, reflecting that the pilot has not been able to tap into a wider range of EE potential. Secondly, the EDR Pilot makes one-off payment based on EE projects'

---

[73] In 2016, the government decides to amend the rules to allow unproved DR successful in the first 'transitional arrangements' auction to offer in the main capacity auction for delivery in 2020-21.

first-year capacity performance, meaning that its capacity price is not directly comparable with the GB Capacity Market. In the first and second EDR auctions, the weighted average capacity price are £229/kW and £203/kW respectively. This is on par with the GB Capacity Market, only if the procured EE capacity can maintain the same level of peak savings for 11-12 years. Thirdly, in the second EDR auction, resource providers can choose the delivery year of either 2016-17 or 2017-18. Nearly 59% of allocated budget goes to EE projects opting to deliver in the winter of 2017-18, suggesting that project developers may find it difficult to participate over the one-year programme timescale as required for the first auction.

7.5.2. Pattern of DR and EE procurement

For each delivery year, after the main forward auction, capacity providers can replace or take on additional obligations from reconfiguration auctions or bi-lateral transaction. Capacity replacement may be necessary due to resource retirement, delay in construction and procurement target change. Evidence from ISO-NE and PJM shows different procurement pattern between generation and demand-side resources, and even between DR and EE.

Relative to generation, demand-side resources tend to shed a large part of their obligation after the main forward auction (Table 7-3). In ISO-NE, the replacement rate for generation is 8-10% for 2012-15, whereas that for demand-side resources is 19-46% over 2011-15. In PJM, while generation replaced 4-6% of its obligations for 2011-14, the rate for demand-side resources is 24-55% for 2011-15.

Table 7-3. Replacements of capacity commitments in the PJM Reliability Pricing Mechanism

	2011-12	2012-13	2013-14	2014-15	2015-16
ISO-NE					
Demand Resources					
Base Auction Cleared (MW)	2,778	2,868	3,260	3,467	-
Final Commitments (MW)	2,255	2,012	1,665	1,888	-
% of Change	-19%	-30%	-49%	-46%	-
Generation					
Base Auction Cleared (MW)	-	34,128	34,239	33,450	-
Final Commitments (MW)	-	30,816	30,960	30,871	-
% of Change	-	-10%	-10%	-8%	-
PJM					
Demand Resources					
Base Auction Cleared (MW)	1,903	9,413	11,684	16,021	16,644
Final Commitments (MW)	851	7,124	8,490	9,493	12,150
% of Change	-55%	-24%	-27%	-41%	-27%
DR					
Base Auction Cleared (MW)	1,827	8,753	10,780	14,943	15,454
Final Commitments (MW)	774	6,499	7,465	8,211	10,624
% of Change	-58%	-26%	-31%	-45%	-31%
EE					
Base Auction Cleared (MW)	76	660	904	1,078	1,190
Final Commitments (MW)	77	625	1,025	1,282	1,526
% of Change	1%	-5%	13%	19%	28%
Generation					
Base Auction Cleared (MW)	132,280	131,877	148,161	-	-
Final Commitments (MW)	126,504	124,765	139,119	-	-
% of Change	-4%	-5%	-6%	-	-

Source: PJM State of the Market Reports; Monitoring Analytics (2013)

In PJM, DR and EE also demonstrate different patterns in taking up capacity obligations. For 2011-16, DR shed 26-58% of its obligations after the main forward auctions by acquiring replacement capacity. As argued by Monitoring Analytics (2013), the substantial replacement of DR is likely due to its provider's bidding strategy of offering in the main forward auctions without sufficient commitment from customers or a well-devised plan to develop DR. This probably reflects the difficulty in securing customer commitment on a three-year forward basis, while excessive replacement risks distorting the main forward auctions where most of capacity is procured.

By contrast, EE appears more reliable in 'maintaining' its obligations, with the final commitment for 2013-16 ending up 13-28% higher than that cleared in the main forward auctions, suggesting the high confidence of EE providers in delivering their obligations. However, more reliable programme planning is unlikely to be the reason. This is because, to offer into three-year forward auctions, EE programmes still face many uncertainties from technological, regulatory and market changes and dynamics in future capacity auctions (Jenkins et al., 2011). One possible explanation is that resource providers ‘under-bid’ in the first place. Once they can better predict capacity performance closer to delivery year, they may take up additional capacity obligations.

7.5.3. Participation by end-use and sector: experience in PJM

Providers of DR and EE in the PJM Reliability Pricing Mechanism show a distinct tendency in targeting end-uses and sectors: while most of DR is from manufacturing, heating, ventilation and air conditioning (HVAC) and on-site generation and from commercial and industrial (C&I) customers, lighting measures of residential and commercial customers contribute most of the EE capacity. As for DR, the *Demand Response Operations Markets Activity Reports* of PJM publish information on the source of registered capacity of the Load Management programme[74] (Fig.7-7). By end-use, for 2012-16, major sources of DR are manufacturing (28-39%), on-site generation (21-23%) and HVAC (22-29%). Lighting made up only 6-8% of the registered capacity, with the contribution of refrigeration (2-3%) and water heating (1%) being even smaller. By contrast, most of the EE capacity came from lighting in commercial and industrial (45% of total EE capacity) and residential (40% of total EE capacity) sectors (Keech, 2015). HVAC only comprised 3% of the total EE capacity

---

[74] In PJM, the Load Management DR includes the DR capacity participating in the RPM and that forming part of the Fixed Resource Requirement (FRR) plan of Load Serving Entities.

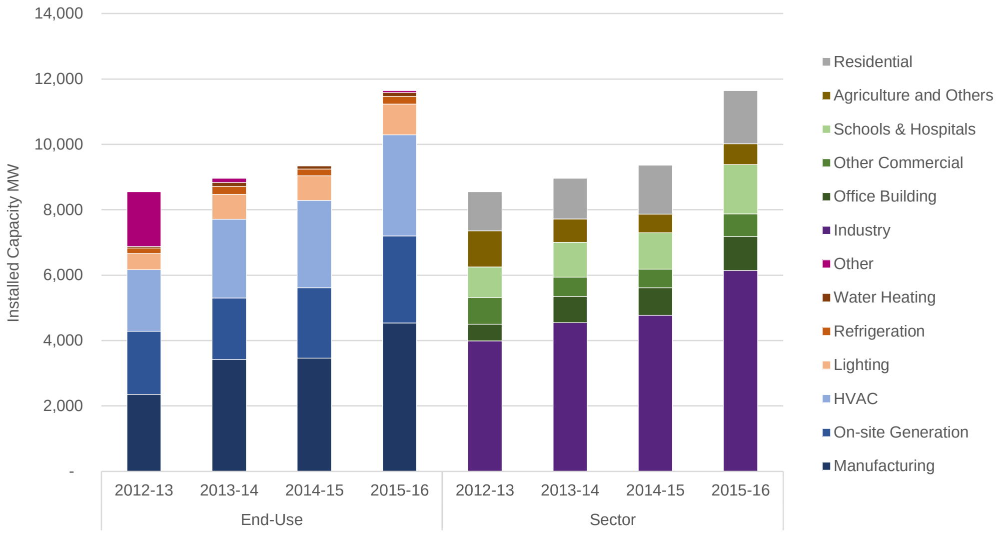


Fig. 7-7. Registered MWs of Load Management Programme in PJM by end-use and sector

Source: PJM Demand Response Operations Markets Activity Reports

By customer sector, industrial customers contributed 47-53% of the registered DR capacity for 2012-16, with the share of commercial buildings (e.g. office and retail) and public sector buildings (e.g. schools and hospitals) being 15-16% and 11-13% respectively. Residential customers only made a small contribution of 14-16%, which is in stark contrast to the significant role residential sector, particularly its lighting measure, has played in providing EE capacity.

The trend of DR and EE to target different end-uses and sectors reflects their distinct nature and the programme focus in developing demand-side resources. From a technological perspective, some end-uses (e.g. HVAC) are more flexible than other (e.g. lighting), thus more suitable for DR. Large market potential of end-use or on-site generation suitable for DR, and economics of customer recruitment and enabling technology, support the business case for focusing on C&I customers to develop DR. However, this may change with smart metering being rolled out to households. As for EE resources, obliged utility programmes dominate in capacity auctions and they traditionally achieve a considerable proportion of peak savings from efficient lighting in residential and commercial sectors.

7.6. Discussions

7.6.1. Relationship between DR and EE

The experience of ISO-NE, PJM and GB Capacity Market reflects the distinctive drivers behind the participation of DR and EE. Although the design of integration mechanism and market conditions play a key part, the participation of EE is more heavily influenced by regulatory provision. This can be seen from the dominance of obliged utilities in offering EE resources and the correlation of regulatory EE activities and scale of contribution in the capacity auctions of ISO-NE and PJM, which can be explained by how EE projects are funded. For 2011-14, the payment from the ISO-NE Forward Capacity Market only covers 3-12% of the total expenditure of obliged utility EE programmes in Massachusetts, New Hampshire, Rhode Island, Vermont and Connecticut (NEEP, 2016). In other words, peak saving is only a small part of the benefits of EE and other funding sources, especially for obliged utility programmes, are key to incentivising the investment.

In the UK, recent changes in the obliged utility EE programmes (i.e. Energy Company Obligation) lead to a focus on gas use in the residential sector, while non-residential sector is largely excluded from obliged utility programmes (Rosenow and Eyre, 2015). In this context, besides utilising EE as a capacity resource, the EDR Pilot is also intended for promoting electrical EE, while most stakeholders see ‘feed-in tariff for EE’ (see Eyre, 2013a) as a more appropriate policy option. However, this logic is flawed as the evidence above shows that peak saving is only a small part of the benefits of EE, and that regulatory ambition for EE drives its contribution as a capacity resource, not the other way around.

By contrast, most of the value of DR comes from contributing to the capacity adequacy. It means that the economic case of DR is sensitive to the capacity payment as well as market requirements (e.g. product definition and delivery requirement), just as shown in ISO-NE, PJM and GB capacity markets.

Moreover, as seen in PJM, DR and EE tend to come from dissimilar end-uses and customer bases, largely due to technological, market and programmatic reasons. It implies that, as discussed in Goldman et al. (2010), programme-level coordination of DR and EE is not yet widespread. However, this pattern does suggest the complementary relationship of DR and EE, as two resources, in realising the demand-side potential of contributing to the capacity adequacy. It also underlines the value of integrating both DR and EE in capacity auctions for diverse, cost-effective procurement.

7.6.2. Capacity products

The design of capacity products entails a balanced consideration of two aspects. Firstly, it should reflect the operational needs of system. As seen earlier, the growth of DR with limited dispatchability and need to ensure capacity adequacy outside traditional summer peaks led PJM to introduce capacity products with higher delivery requirements, and to 'restructure' the product definition. Different from ISO-NE and PJM where the capacity value of EE is based on the average peak savings in summer and winter, the EDR Pilot only focuses on savings during 4pm-8pm of working weekdays in winter. This is sensible, given that these are typical peak hours in the GB system and the winter peak is usually much higher than the summer peak (Gavin, 2014).

Secondly, the market potential to provide required resources is another consideration. In PJM, the auction results show that DR with limited dispatchability (i.e. Limited and Extended Summer DR) still dominates the overall DR portfolio, even after five years since the differentiated products were offered. This suggests that high delivery requirements, together with technological and market factors, limit the market potential of DR.

The current design of GB Capacity Market requires DR to deliver whenever system emergencies occur. While it reflects the regulatory intention to crease a 'level playing field' for all resources, industry stakeholders are concerned that the 'one-size-fits-all' approach would limit the long-term growth of DR market, especially given its early stage of development and the low dispatchability of existing products (SmartGrid GB, 2013). Ward et al. (2012) estimated the size of DR resources in GB at 1-1.5GW in 2012, which is below 3% of the winter peak demand. The system operator launched the Demand Side Balancing Reserve (DSBR) programme to procure additional DR from large customers for winters in 2014-16, which requires load reduction within two hours of dispatch only during 4pm-8pm of working weekdays in winter. DSBR auctions for 2014-15 and 2015-16 cleared 330MW and 515MW respectively, although making only small addition to the overall DR market (Bingham, 2015).

The time banded DR under ‘transitional arrangements’ seems to recognise the difficulty of meeting the high delivery requirements in the GB Capacity Market. The short-lived ‘transitional arrangements’, however, pose question on their effect on promoting the DR market before the Capacity Market starts operation in 2017-18. Therefore, with the time banded DR still targeting typical winter peak hours, from the view of supporting the DR market, it is helpful to offer the time banded product in the GB Capacity Market. To minimise the risk of relying on less dispatchable resources, one possibility is to impose a ceiling for their procurement, which is already in place in the ‘transitional arrangements’.

However, the expectation of when and how often dispatch order is *actually* called, which depends on the system operating conditions, also influences the offering of DR. For example, in ISO-NE, while the real-time DR is required to deliver when system emergency conditions occur, it was only dispatched infrequently.

7.6.3. Procurement mechanism

Like other resources, DR and EE may bid into the main forward auctions as well as reconfiguration auctions. In so doing, demand-side resources may face two key challenges. Firstly, the funding may be unstable. Bidding into these auctions means direct competition against other resources – depending on the offers of other resources, there is uncertainty of whether DR and EE clear the auction and the level of payment. For example, the total capacity revenue for DR fluctuated widely in PJM, decreasing by almost 40% from 2010 ($500mn) to 2012 ($320mn) before growing to $800mn in 2015 (McAnany, 2016). This can be problematic for a market of demand-side resources at its early stage of development.

Secondly, forward planning several years before delivery is another challenge. For DR and EE, it entails risk in resource development as well as capacity performance. While many providers already operate on a forward planning basis (e.g. DR aggregators and obliged utilities for EE), and most of DR and EE in ISO-NE and PJM is procured from main forward auctions, it is still important to ensure that the lead-time of capacity market does not constitute undue barrier for DR and EE. As one strategy, the resource provider may bid without firm customer commitment. In fact, as seen above, DR in PJM tends to shed its obligation from main forward auctions. In the GB Capacity Market, more than 95% of DR is without prior performance evidence (National Grid, 2014, 2015). Although this may be a justifiable commercial strategy, it is important that it does not comprise capacity procurement.

In the UK, the perceived difficulty associated with the four-year lead-time leads the government to see year-ahead reconfiguration auctions as more appropriate for acquiring DR (Baker and Hogan, 2014). However, this does not recognise their limitation. In ISO-NE and PJM, most of the capacity is procured in main forward auctions. In the GB Capacity Market, the target for reconfiguration auctions for 2018-19 and 2019-20 is set at about 5% of that in main forward auctions, and would be even reduced starting from 2020-21 (DECC, 2016b). The small procurement target in reconfiguration auctions would suggest fierce competition, especially if there is surplus of capacity. Therefore, over the long run, it is imperative for the GB Capacity Market to remove barriers for DR to participate in the four-year forward auctions, and for the DR market to strengthen its capability for dealing with risks in funding and forward planning.

For the EDR Pilot, there are several issues of its current design with the coordination with forward capacity auctions. Firstly, the EDR auction gives ‘one-off’ payment to EE capacity, while resources in the GB Capacity Market and 'transitional arrangements' are paid by each year. Although this 'one-off' approach gives high certainty to projects, there are downsides such as the difficulty of integrating with the auction model of GB Capacity Market and the risk of favouring measures with shorter lifetime and payback (Mount and Benton, 2015). Another issue is the M&V – while EE measures would persist over years, their capacity value may change. Thus, the 'one-off' approach has the risk of over-paying projects if their capacity value decays rapidly after the first year of delivery. For the capacity procurement, it is valuable to obtain latest capacity value of previous EDR projects to inform peak forecast. In ISO-NE and PJM, the annual qualification of EE should reflect changes in the capacity value. After the payment is made, however, it is challenging to obtain updated project information. One possible solution is to allow EE resources to 'lock in' the auction price via long-term contracts, with requirement of updating their capacity value regularly. Alternatively, it may be possible to undertake research on more standard measures for evidence on their peak impacts over time, although this is difficult for custom measures.

Secondly, different from the main auctions, the EDR Pilot caps the budget for each auction and bid price but runs without a procurement target. Moreover, while the first EDR auction operates on a year-ahead basis, the second one allows resources to deliver in one or two years. These design features make it difficult to estimate, even roughly, the capacity the EDR Pilot can procure for each year and how much to acquire in main forward auctions. For this, it may be possible to set a procurement target that is adjustable based on market conditions, or to schedule the EDR auction before main forward auctions.

Thirdly, the EDR Pilot puts in 'additionality' criteria to limit eligibility for participation to those projects not funded by other government EE schemes and with a payback period of over two years. The objective of only supporting projects that would not otherwise happen is valid from the point of an EE policy. However, it limits the market potential of eligible EE resources and for capacity market, it is not a priority as other resources are not required to show that they would not get built without the capacity payment (Watts and Metternich, 2014).

7.6.4. Interaction with other markets

While this paper focuses on the capacity adequacy, demand-side resources may support the short-term system balancing, by concurrently participating in ancillary markets like reserves and frequency response (Cappers et al., 2013). These parallel programmes have parameters for dispatch (e.g. trigger conditions) different from those in the capacity market but conflict may arise if the same resource is dispatched by capacity market and ancillary services. While this suggests an industry-wide framework for utilising demand-side resources (e.g. Ofgem, 2013a), it is imperative that resources should have the flexibility to choose which markets to offer in, and that participating in these ancillary services does not undermine the incentives in the capacity market. For example, when resources are dispatched to provide both capacity and ancillary services[75], the GB Capacity Market allows adjustments to the baseline for the capacity obligation to avoid 'unfairly' penalising resources (DECC, 2014d).

Moreover, DR and EE can also contribute to the management of local networks (Neme and Sedano, 2012; Strbac, 2008). In the USA, some regional utilities and regulators (e.g. Vermont and Rhode Island) are integrating demand-side resources in the network planning to defer upgrades (Anthony and Foley, 2014; Navigant, 2011). In the UK, the Low Carbon London project explored the feasibility of DR as an alternative to network reinforcement (UKPN, 2014b). While EE delivers 'passive' load reduction, the time, frequency and location for dispatching DR for local network conditions may not well align with those for the capacity market and ancillary services (UKPN, 2014a). In light of these conflicts and synergies, a cross-party framework needs to be established for regulating the use of DR for different purposes.

---

[75] With the exception of short-term operating reserve (STOR) resources with long-term service contract

7.7. Conclusion and policy implications

This paper examines the integration of DR and EE into forward capacity markets. For ISO-NE, EE becomes increasingly important for ensuring capacity adequacy, while the contribution of DR declines due to factors related to changes in market design. In PJM, however, DR leads the contribution of demand-side resources and EE only plays a small role. The procurement of these two resource types in the GB Capacity Market is still at an early stage, due to factors of mechanism design, market conditions and regulatory provisions.

The participation of EE is more heavily influenced by the stringency of utility EE obligations, while that of DR appears sensitive to the capacity payment and delivery requirements. The complementarity of DR and EE in targeting end-uses and customer sectors underlines the value of integrating these two demand-side resources into forward capacity markets.

The definition of capacity products makes DR and EE resources ‘tradable’, and should reflect the needs of system and resources’ market potential. It is valuable to introduce capacity products with lower delivery requirements to support the growth of market (e.g. DR in the UK), if they can make meaningful contributions to the capacity adequacy.

In offering in forward auctions, DR and EE resource providers may face risks of unstable funding and forward planning. Over the long-term, it should be the imperative of capacity market and policy makers to remove barriers for the participation of these demand-side resources, and to strengthen the capability of market to deal with these risks. For the EDR Pilot in the UK, it is important to ensure the coordination with forward capacity auctions, particularly in terms of the procurement procedures.

8 | Conclusion

This chapter synthesises high-level findings and implications of the thesis. It aims to connect the conclusions in each empirical paper into a coherent argument and address the ‘so-what’ aspect of the thesis. There are four parts: 1) how the findings of each paper contribute to the overarching research question and formation of argument; 2) policy implications for the design of a forward capacity market, the EDR Pilot in the UK and the EE regulatory framework; 3) future research areas; and 4) contributions of this thesis.

8.1. Overarching argument – bringing empirical papers together

This thesis poses a central question of ‘*what role a forward capacity market can play in promoting electricity use reduction’*. There are two aspects, namely 1) whether a forward capacity market can be a *primary* policy vehicle for incentivising investment in electric EE measures; and 2) as a mechanism to ensure capacity adequacy, whether and how a forward capacity market can promote electricity use reduction *as a capacity resource*.

The argument of this thesis consists of two strands, based on these four empirical papers:

1. A forward capacity market can only play a minor role in advancing the policy objective of incentivising investment in electric EE measures (*in response to Hypothesis 1 and Hypothesis 2 as set out in Chapter 1*);
2. However, it is a viable mechanism to reward capacity value of electricity use reduction, which requires appropriate definition of capacity product, regulatory support and removal of barriers for participation (*in response to Hypothesis 3 as set out in Chapter 1*).

The first strand of argument is based on Chapters 4-6, while the second strand draws upon Chapter 7. Here, an overarching argument is constructed from sub-arguments made in each paper. A ‘deep dive' into the headline conclusions of these chapters and how they feed into the overall argument is provided. It revisits the central assumptions or hypotheses as set out in Chapter 1 and relates to the findings in empirical papers for gauging whether these hypotheses are supported or otherwise.

8.1.1. Can the forward capacity market be a primary vehicle for incentivising investment in electric EE?

The proposition that a forward capacity market can be a *primary* vehicle for incentivising investment in electric EE measures makes two central assumptions:

- **Hypothesis 1** – The incentive based on peak savings provides *comparable* financial support as that based on energy savings to EE measures. In other words, given that many customers do not face time-differentiated tariffs and thus investment payback depends on energy savings, peak- and energy-savings should be more or less aligned for it to be logical of an energy-saving policy to focus solely on peak savings; and
- **Hypothesis 2** – A savings-based approach for giving financial incentives, as implied by the design of the forward capacity market, would be *effective* for driving electric EE investment in *various* customer segments. If it is adequate to rely on the forward capacity market as a primary vehicle, it should promote participation from diverse project types and customer segments. That said, a savings-based approach and its designs may not create undue barriers for participants to offer projects and earn payment.

Nonetheless, these two central assumptions are not supported by findings in this thesis.

- **Hypothesis 1**

For Hypothesis 1, the peak- and energy-savings of EE measures are not well aligned, whose relationship can vary significantly among measure types and between seasons (Chapter 4). While the characteristics of electricity demand (e.g. demand profile, system peak period) differ across regions, a review of utility EE programmes in nine jurisdictions in North America (Section 4.6) shows that residential lighting and residential water heating tend to achieve greater peak savings in winter weekday early evening peak periods, while C&I lighting and residential appliances appear to deliver higher peak savings in summer weekday afternoons. Lighting, particularly residential lighting, show greater variance of seasonal peak demand. Regarding the relationship of peak- and energy-savings (i.e. savings in peak periods vs. those in non-peak periods), EE measures of residential and C&I space cooling and C&I lighting tend to make greater peak savings relative to non-peak savings for summer peak period of weekday afternoon. For winter peak hours of early weekday evening, residential lighting may deliver greater peak savings relative to non-peak savings. In a nutshell, with the same level of energy saving, some measures are better at reducing system peak demand than others.

The implications are two-fold. First, for customers' investment decisions, financial incentive based only on peak savings is to benefit a subset of EE opportunities more than others, even if the potential and cost of saving energy would be similar. Based on the review in Chapter 4, efficient air conditioning and lighting (particularly residential lighting) measures may well benefit most in summer- and winter-peaking systems respectively, because of their 'peak-ier' demand profile (i.e. larger share of energy use happens in system peak periods). As seen in Chapter 5, in the EDR Pilot that remunerates projects entirely on their peak impacts, most of the projects focus on lighting measures in the UK. Its interim evaluation report suggests that besides a lower complexity and M&V requirement, the close alignment of lighting use and the GB system peak is one key driving factor (Section 5.5). These observations point to the risk of favouring EE measures with a 'peak-ier' demand profile, especially those with a low cost of peak saving, and penalising others, even if those measures can save overall electricity use at the same cost.

As mentioned earlier, the peak demand-related pricing signal is weak, or even non-existent, for many retail customers. If an incentive scheme only bases financial support on the peak savings of EE projects or measures, retail customers may well focus on EE opportunities with a low-cost level for energy saving and a ‘peak-ier’ demand profile, and assign secondary priority to those of a less ‘peak-ier’ demand profile. From the point of a forward capacity market, this adds value due to the competitive price pressure from lower-cost peak savings from EE measures and potentially a lower capacity clearing price, thus benefiting all customers. However, from the point of energy efficiency and climate change policies, the downside is that not all cost-effective EE opportunities in terms of energy saving may be captured – this is undesirable given the urgency of strengthening the efforts of climate mitigation, not the opposite.

Second, as seen from ISO-NE and PJM (Section 4.3), the strength of capacity value as realised from participation in the forward capacity market, at least for now, tends to be low. For example, during 2011-13, the gross proceeds from the forward capacity market only contribute less than 15% of the total funding for utility EE programmes in the states covered by ISO-NE and PJM. In other words, the current market conditions (e.g. relative share of CAPEX and OPEX of generation and other assets) mean that even for EE measures with a low cost and ‘peak-ier’ demand profile, the strength of incentive from the forward capacity market only is likely to be limited.

While in principle the financial incentive can be based on both energy- and peak-savings, it is technically impossible for a forward capacity market given its fundamental role to remunerate *capacity value*, not energy value, of resources. If a liberalised market has set up a forward capacity market, as discussed in Section 2.4, it essentially further differentiates products in the electricity market (i.e. energy, capacity and ancillary service) whose value is recognised and remunerated in separate markets (i.e. wholesale energy market, capacity market and ancillary market). In theory, if EE resources can bid their energy-savings into the wholesale energy market, in a way somewhat similar to how generation and DSR have done, it should open a door for EE resources to access funding for their energy value. However, as briefly noted in Section 2.5, this idea remains untested and the practical barriers for so are almost insurmountable.

In summary, the incentive scheme solely based on peak savings may well favour some EE measures over others and miss certain cost-effective opportunities for energy saving, let alone the strength of such an incentive tends to be limited. However, this conclusion should be revisited in the future, with the electricity system and markets undergoing significant changes (e.g. CAPEX and OPEX profiles and intermittency of assets, importance of capacity value as opposed to energy value, growing penetration of smart metering and time-differentiated retail tariff).

- **Hypothesis 2**

For Hypothesis 2, a savings-based approach for giving financial incentives, as implied in the design of a forward capacity market, appears to be effective in capturing only a subset of electric EE improvement opportunities in terms of customer and project types. That said, several intrinsic features of the savings-based approach create barriers for some customer and project segments to access the potentially additional funding from a forward capacity market.

Chapter 5 is an empirical analysis of how a savings-based approach is used to acquire electric EE resources in North America, Europe and the UK. A savings-based approach is valuable for its flexibility to fit with diverse project and customer needs, particularly for acquiring savings of customised projects and non-lighting measures that are a priority for an ambitious energy-savings target. However, it tends to be used for *non-residential* customers and in many cases for projects above a certain size, to ensure efficient scheme operation. Even among non-residential customers, complex participation and M&V requirements (e.g. for energy- and peak-savings, and sometimes involving dedicated metering/modelling) may pose challenges for smaller organisations, given their often-limited internal resources.

Chapter 6 complements Chapter 5 by examining whether a savings-based approach would be effective in procuring savings in the *residential* sector, using the example of the EDR Pilot in the UK. With a case study of social housing in Britain, it finds that while there are opportunities for reducing electricity use in lighting, appliances and heating, incentives based on peak savings are unlikely to be attractive and would disadvantage EE measures like insulation or efficient heating that may deliver great economic savings given the large share of heating expenses in electrically heated homes. For opportunities *within* households, due to constraints like split incentive and lack of control on how tenants use electricity, the obligation to deliver committed peak savings, M&V and a limited scope of payback poses challenges and risks for entities aggregating such residential EE resources and bidding them in the EDR. For communal areas in social housing, the minimum project savings, cash-flow constraint and limited organisational capabilities also create barriers for housing providers.

These barriers noted in Chapter 5 and 6 are also ‘flagged up’ in the interim evaluation of the EDR Pilot that focuses on the participation of non-residential customers (BEIS, 2017a). The first phase of surveys and interviews were conducted with organisations engaged with the Pilot (i.e. registered interest and/or completed at least one stage in the ‘customer journey’ from awareness, application to auction and agreement signing). It is shown that organisations successful in winning capacity contracts have already had EE project propositions (e.g. scoping to fully designed) before awareness of the Pilot and these propositions can be easily adjusted to meet the requirements of the Pilot with minimal work (e.g. flexible internal approval). Most of them see the EDR funding as incremental ‘boost’ to the investment case of these projects, for meeting the investment return hurdle rate or gaining leadership buy-in. Moreover, all of them have dedicated resources, either internally or from external consultants, to support the application and bidding. At the other end, for organisations not applying, common barriers as cited are the challenging time-scale (i.e. ~9 months between auction and delivery), requirements of participation processes (e.g. application, data requirements, bidding, minimal savings especially if aggregating over multiple sites is needed), uncertainty of clearing auctions and financial risk of capacity underperformance. With a relatively low level of funding – for many projects, the EDR funding only covers 10-15% of project costs – many organisations perceive that there is no strong case for sourcing dedicated resources to support participation or proposing a new project from scratch. It is particularly true for organisations with limited expertise of EE projects.

Regarding the project types, as noted in Section 5.5, almost 99% of the allocated EDR funding goes to lighting projects, largely due to the high coincidence of lighting use and system peak, the straightforward nature of lighting projects even if adjustments are needed (e.g. aggregation over multiple sites to meet minimum savings) and the possibility to 'deem' peak savings, thus reducing the complexity of M&V and financial risk of underperformance.

While the EDR evaluation is still ongoing, these interim findings are broadly consistent with those in Chapters 5 and 6 that a savings-based approach modelled after a forward capacity market would be more suitable for certain customer or project types (e.g. lighting in large customers with dedicated resources to support application). With a high requirement of data input and expertise in dealing with the application (e.g. auction), uncertainty in securing funding and financial risk if underperforming, offering electric EE projects into a forward capacity market or a similar scheme appears to disadvantage many of the customers that may not have the requisite resources or find it difficult to build an investment case for doing so. In the 2nd auction, a number of criteria were revised to lower the hurdle for participation (e.g. minimum savings dropped from 100kW to 50kW, up to 2 years for project delivery as opposed to 1 year in the 1st auction, simplified evidence needs, potential of leaving up to 40% of the proposed peak savings unspecified at application). However, although the participants generally welcome such changes, many still find it burdensome or not worthwhile to deal with the savings-based approach modelled after the forward capacity market, given the associated risks. After all, there is also a balance to be struck between relaxing criteria to facilitate customer participation and the efficiency and reliability of procuring electric EE as capacity resources. As further discussed in Section 8.2, in the context of efficient operation of a forward capacity market, there is a limit to the extent to which market rules can be relaxed to support electric EE, questioning the assumption that it can be a primary vehicle for driving EE.

In relation to the organisational aspects of the barriers for EE investment (Section 2.2.1), the savings-based approach does not appear to alleviate the barriers faced by customers, particularly for smaller organisations and those providing social housing. In fact, it increases the complexity of accessing funding and the need for dedicated resources that may be absent in many places (e.g. knowledge of scheme and application process, available staff time, data needs for M&V, expertise for dealing with aggregation and performance risks). Even with the potential of financial support, for now at least, it is not attractive enough for smaller organisations to justify developing these dedicated resources. Moreover, in the case of social housing in the UK, the obligation to deliver committed savings or face penalty raises the investment risk borne by customers whereas in the past energy retailers bear the regulatory consequence of under-delivery in savings. This weakens the case for seeking funding from schemes using a savings-based approach even further. Finally, reducing peak demand does not align with the priority in ensuring affordability and promoting tenant benefits in social housing. It is another organisational factor discouraging social landlords from developing resources to support any prospective application.

So, what does it mean for the role of a savings-based approach for giving financial incentives? First, the empirical evidence demonstrates the flexibility of this approach, thus its potential to fit with diverse customer and projects needs as well as market trends. While traditional schemes may give financial support based on the type of measures or size of investment, it is highly valuable to complement them with those using a savings-based approach, thus capturing opportunities that may not readily fit with traditional schemes (e.g. customised projects or more custom measures such as operational measures). Second, a savings-based approach would not be effective as the *primary* approach to giving out financial incentives *directly to customers*. For more standard measures/projects, and for smaller non-residential organisations and residential sector, this thesis underscores the need of a simple scheme design (e.g. prescriptive incentive in the form of retail/upstream discount, rebates) to give easy-to-access financial support to customers or sectors that may it burdensome to participate in savings-based schemes. That said, the savings-based approach should be *one of many instruments*, as opposed to being a *'catch-all silver bullet'*, to give financial incentives in the non-residential EE policy mix.

However, development in the metering infrastructure, particularly the penetration of smart metering in households, and the relevant M&V methodology may reduce the barriers and improve the economics related to M&V for smaller customers. As noted in Franconi et al. (2017), 'M&V 2.0' that combined more granular electricity use data at the end-use level and automated analytics enabling 'ongoing, near-real-time savings estimates' would accrue multiple benefits, including whole-building interval data, early feedback to support scheme targeting and reduce *ex post* data needs for M&V, and locational and temporal load impacts of EE measures. While the tools and protocols for 'M&V 2.0' are being developed, there is potential to utilise the rich smart metering data and enhanced computing power and data analytics (Franconi, 2016). Presumably, this would reduce the cost and complexity of M&V, particularly for less standardised measures and smaller organisations, thus supporting the deployment of savings-based incentive schemes (e.g. 'pay-for-performance' schemes in the U.S.).

- **Summary**

The fundamental design of a forward capacity market is a competitive market mechanism to procure *capacity value* of resources and remunerate based on the *delivery of capacity value* that can be verified. From the point of customers, offering electric EE resources into forward capacity auctions can be seen as a funding scheme that employs a savings-based approach to reward based on the peak demand impacts of these resources. The argument that a forward capacity market can be a primary vehicle for incentivising electric EE investment is flawed in two areas.

First, peak- and energy-savings are not necessarily well aligned across measure types and seasons. An incentive scheme solely based on peak savings may well favour some EE measures (e.g. air conditioning in a summer-peaking system, and lighting in a winter-peaking system) over others and miss certain cost-effective opportunities for energy saving, let alone the strength of such an incentive tends to be limited.

Second, while a flexible savings-based approach has its benefits, its design and requirement (e.g. minimum size, M&V, obligation to deliver savings) may impose barriers for participation, particularly for smaller non-residential organisations and residential customers. From the point of a forward capacity market, the savings-based approach is the only way to remunerate the capacity value and allow competition and trading among resources. It is flexible in that EE projects can participate as long as their impacts can translate into *capacity savings*, i.e. the currency in a forward capacity market, regardless of how savings are achieved. To ensure the market integrity and system reliability, a forward capacity market needs to put in place rigorous procedures for acquiring and verifying capacity resources including electric EE – this is seen across three forward capacity markets in PJM, ISO-NE and GB. While as discussed above these requirements may create barriers for some organisations to take part, they are essential features for a market mechanism to address the 'missing money' issue in the liberalised market, which is not initially designed to incentivise electric EE investment. In face of these, while 'a direct route' to a forward capacity market provides a prospect of additional funding source, it is unlikely to be effective in procuring resources from all sectors where electric EE opportunities reside. That said, a savings-based approach may not be effective as a *'catch-all silver bullet'* to capture all potential EE resources from non-residential customers and households, even with its flexibility.

What these findings suggest is that allowing EE projects to offer in a forward capacity market is valuable as an additional source of funding and accrues customer benefits. Moreover, a savings-based approach for rewarding projects based on their energy- and/or peak-savings is helpful in capturing additional opportunities and should be deployed more widely in the design of incentive schemes. Nevertheless, a savings-based scheme that rewards *solely* peak savings and employs a competitive auction for procurement, following the core design of a forward capacity market, can only benefit a sub-set of electric EE opportunities (e.g. lighting in large non-residential customers for a winter-peaking system). Given the imperative of more ambitious climate mitigation and energy-saving targets, it is illogical to primarily rely on a forward capacity market to incentivise electric EE. Indeed, this is opposite to what the UK government assumes in their position of using the forward capacity market as a primary vehicle for incentivising electric EE and removing the need to do so via regulatory interventions. In fact, this thesis underscores the importance of regulatory provisions to incentivise electric EE investment, particularly those using a simpler design that reduces not increases the complexity of participation and rewarding both energy- and peak-savings.

While this thesis is about the forward capacity market, it focuses on the key designs shared with other types of capacity markets (e.g. Section 2.4.5) – the potential barriers customers face in accessing funding from the forward capacity market may also exist in the capacity market with a shorter forward period. Moreover, considering the difficulty in bringing about EE projects in a short lead time (e.g. in the case of EDR Pilot in the UK), it can be postulated that the capacity market with a short forward period may be even more unlikely to become a primary vehicle for incentivising electric EE.

8.1.2. Can the forward capacity market promote electricity use reduction as a capacity resource?

Even if it would not be adequate to rely on a forward capacity market as a primary vehicle to incentivise electric EE investment, this thesis shows that it is still valuable to integrate electric EE in a forward capacity market. As discussed in Section 2.5, integrating cost-effective electric EE resources in capacity procurement and system planning would help increase the competition among resources and lower the cost of acquiring capacity, thus benefiting customers. By lowering the peak demand, additional customer benefits can also come from lower wholesale energy price.

In a way, a forward capacity market is like the 'least cost' or integrated resource planning – it recognises the value of electricity use reduction, as well as other demand resource like DSR, as cost-effective alternative to generation. The difference is that a forward capacity market is not a regulatory process but relies on competitive auctions and market forces to determine the price and quantity for capacity procurement.

It is against this backdrop that this thesis considers *how the mechanism needs to be designed* to allow demand-side resources to be integrated in a forward capacity market and compete against generation capacity. As noted in Section 2.4, it is beyond the scope of this thesis to examine in depth whether a forward capacity market is the best option to ensure adequate and right mix of resources in a restructured market where the long-term capacity adequacy has emerged as an issue. Given that forward capacity markets are set up in several major markets (e.g. PJM, ISO-NE, GB and France), this thesis focuses on the design of integration mechanisms, *if* a decision is made to have a forward capacity market.

Chapter 7 examines the experience of PJM, ISO-NE and the EDR Pilot in acquiring electricity use reduction as a capacity resource. The empirical experiences confirm that appropriate capacity products can be designed to value the contribution of electric EE projects to the capacity adequacy (i.e. demand reduction during system peak hours), and make electricity use reduction a tradable commodity. Given that electric EE can achieve non-dispatchable peak savings, its capacity value is typically defined as average peak savings over system peak hours, while the capacity value of dispatchable DSR is the difference between customer load during a system event and baseline as determined from the load in recent similar days and right before the DSR event. For promoting demand-side participation in the forward capacity market, it is valuable to integrate electric EE, as it complements DSR that is already procured in many capacity markets but tends to target different end-uses and customers from electric EE.

A robust M&V regime already exists to verify peak demand reduction from electric EE and DSR, for substituting generation capacity (Section 7.3). As seen in PJM and ISO-NE, large-scale, regular load research can be used to allow a ‘deemed’ approach for estimating the load impacts of standard measures (e.g. lighting, residential appliances), which would simplify the M&V for those measures while ensuring rigorous peak impact estimation to support system reliability.

However, this thesis also shows that the design of integration mechanism, market conditions and regulatory provisions are key factors influencing the level of participation of electricity use reduction and DSR in a forward capacity market. For DSR, the delivery parameters (e.g. response time and frequency) as defined in various capacity products, and market design features (e.g. price floor, ‘must-offer’ requirement, as discussed in Section 7.4) are shown as key factors when DSR resources assess the business case based on market conditions. For electric EE, by contrast, the stringency of utility EE obligations (e.g. energy efficiency resource standards, supplier obligation) and the strength of financial support outside the forward capacity market drives the participation of electric EE in forward capacity markets of PJM and ISO-NE. There are two noteworthy points. First, this observation supports the findings for Hypothesis 1 (Chapter 4-6) that participation in the forward capacity market may not be the primary driver for electric EE investment but rather the opposite. Second, a stronger regulatory provision for financial incentives for EE investment is necessary, to increase the participation of electricity use reduction in forward capacity auctions and realise the customer benefits in doing so.

One important issue is whether projects already supported by regulatory incentive schemes (e.g. supplier obligation, policy incentive schemes) should be allowed to offer in capacity auctions. In the EDR Pilot, it is not allowed due to concerns about the ‘additionality’ of savings, given that at least one government incentive scheme is already supporting them. However, this thesis finds three flaws in this argument. First, a forward capacity market, by definition, is not designed as an incentive scheme for EE. Given that other resource types (e.g. generation) are not subject to this ‘additionality’ requirement (e.g. not receiving financial support from regulatory sources), it is not reasonable to subject electric EE projects to such a requirement. Second, the ‘additionality’ can be interpreted as an economic efficiency issue, i.e. the incentive payment is indeed supporting the investment that would not have had occurred otherwise. It is essentially about whether customer benefits can be maximised. However, given the inadequacy of a forward capacity market on itself to incentivise electric EE, disqualifying EE projects supported by regulatory incentive schemes from offering may well limit the scale of bids that would be put forward, even if their participation in the capacity auctions would reduce clearing price and increase customer benefits overall. Third, as seen in some ISO-NE states (Section 7.5), instead of paying directly the customers receiving regulatory incentives, it is possible for utilities or regulators to reduce the ‘dead weight’ by channelling the capacity payment to strengthen other aspects of regulatory EE schemes or reduce customer bill surcharge that is typically funding those schemes.

Finally, in the long run, it is also important to ensure the removal of barriers for demand-side participation, to strengthen the market capability to address risks of unstable funding and forward planning with appropriate business models (e.g. aggregation) and for the EDR pilot specifically, to coordinate with the central auction if electricity use reduction is procured separately.

8.2. Policy implications

This section discusses key implications for 1) the design of EDR as a mechanism for acquiring electric EE capacity and 2) policy provisions to support electric EE, including the use of a savings-based approach, and its participation in a forward capacity market.

8.2.1. Design of EDR as a mechanism for procuring capacity from electric EE projects

This thesis sets out to challenge some of the policy assumptions behind the EDR Pilot. Based on the analyses in the preceding four chapters as well as the interim evaluation outcomes, it shows that while the pilot and its approach have value, it is to benefit from changes in some of the design features and more importantly, a fundamental re-think about its position in the mix of policy options to support electric EE investment.

To start with, the mechanism allowing electric EE projects to bid in the GB Forward Capacity Market and be rewarded for their capacity value should be sustained, given the benefit of lowering capacity acquisition cost and avoiding ‘peaker generation’ as evidenced by the experience in ISO-NE, PJM and the two EDR auctions. For the moment, the EDR Pilot procures capacity outside of the GB Capacity Market on a one- or two-year forward basis, at a price as bid, with a budgetary constraint rather than a procurement target. It gives a one-off payment based on verifiable first-year capacity delivery and requires a two-year minimum project payback. As discussed in Section 7.6, these features are inconsistent with the GB Capacity Market and there are two broad options for positioning the EDR within the GB Capacity Market.

One option is to fully integrate the EDR in the GB capacity auctions, subjecting electric EE to the same rules as other capacity types. However, a number of issues remain that the Pilot is not able to scrutinise. First, while the second auction and the interim evaluation shows the value of a longer lead time (i.e. two years) for project implementation, it is unclear if the four-year forward window, as in the main auction for the GB Capacity Market, would support or undermine the investment case for bidding. Second, if electric EE projects are paid annually rather than in a one-off payment, it is likely to cause cash flow issues for many organisations without a cash-rich balance sheet. For those requiring a quick payback, this payment model with the relatively low funding level would further weaken the attractiveness to customers. Moreover, the pay-as-bid model in the EDR Pilot is inconsistent with the pay-as-clear approach in the GB capacity market. Addressing these inconsistencies may affect the amount of electric EE that customers would put forward. Theoretically, a full integration of electric EE in the GB capacity auctions can promote competition and market efficiency. However, the decision should be based on further research on the customer benefits, particularly if subjecting electric EE to the GB capacity market rules would greatly reduce the potential offers from EE customer projects.

The other option is to continue with the EDR as a separate mechanism but with an improved coordination with the GB capacity auctions. This gives flexibility of policymakers in setting the parameters for auctions and allowing the EE market to gain expertise with the approach based on the forward capacity market. However, as discussed in Section 7.6, it is important to ensure that project savings are regularly verified to a satisfactory level as required for system reliability and the procured EE capacity is reflected in the target in the GB capacity auctions to avoid ‘double acquisition’.

Whichever the chosen option, evidence in this thesis and the interim evaluation suggest that the two-year minimum payback requirement should be lifted. First, resources in the GB Capacity Market are not subject to any ‘additionality’ requirement, i.e. showing that without the capacity payment they would cease to operate. Second, even with the two-year minimum payback, only 57% of the capacity acquired in the 1st EDR auction can be seen as ‘additional’ (BEIS, 2017a). This raises a question about how effective this ‘additionality’ filter would be – given that many organisations cite it as a barrier, removing it may well deliver higher benefits by increasing the participation of electric EE projects (Section 8.1). Third, the approach of providing incentives based on verifiable peak savings may only have a limited role in driving electric EE investment. Indeed, it is more sensible to perceive the EDR as a mechanism to reflect the capacity contribution of electric EE in a market place. Therefore, the additionality becomes a less salient requirement and should not become a barrier preventing electric EE from offering.

8.2.2. Policy provisions to support electric EE and its offering in a forward capacity market

A shown in this thesis, a forward capacity market is unlikely to be the primary vehicle driving the electric EE investment. Therefore, for more energy efficiency and carbon mitigation targets, it is necessary to strengthen the regulatory provisions, including financial incentives under them, which sit alongside the mechanism for integrating electric EE in the forward capacity market and to a large extent drives the latter. A number of policy implications are discussed below.

- **Financial incentives under a regulatory framework (e.g. utility EE obligation) are key to supporting the electric EE investment and its participation in the forward capacity market to reduce the need of generation capacity.** A policy solution to ensure capacity adequacy can only play a minor role in incentivising electric EE and does not align with the customer payback incentive and the policy objective of carbon mitigation. For ISO-NE and PJM, the forward capacity market revenues only contribute a small part to the expenses of utility EE programmes. There is also evidence that in ISO-NE, most of EE capacity is from obliged utility EE programmes, suggesting a limitation of capacity market in incentivising electric EE on its own. As shown in the EDR, the approach based on a forward capacity market tends to favour only a subset of electric EE opportunities and creates barriers for customers to access the potential funding – with a relatively low level of incentive, it is not an attractive value proposition for customers to bid in forward capacity auctions and obtain rewards to support project finances. Thus, valuable as it is to allow electric EE to compete against other resources in forward capacity auctions, it cannot substitute the need for financial incentives provided under a regulatory framework to support electric EE, which should be at the centre of policy deliberations. Moreover, as shown in ISO-NE and PJM, it is the strength of regulatory provisions to support electric EE that drives the scale of participation of electricity use reduction in capacity auctions, not the opposite (Section 7.5). As discussed in IEA (2017), a number of market-based instruments exist to distribute financial incentives under a regulatory framework, such as market-wide energy efficiency auction and utility obligation mobilising ESCos. Once customers receive incentives from schemes under the regulatory framework, it is an issue whether they can still bid the project's peak savings in a capacity auction and get payment. The EDR does not allow projects already receiving other government funding to participate; in PJM and ISO-NE, the common practice seems to be that when customers receive incentives from utility obligation schemes, the right to bid peak savings in the forward capacity market is renounced by customers. It is instead the utilities that bid peak savings from the EE portfolios and receive the capacity payment to reduce bill surcharges or strengthen parts of the EE portfolios (Section 7.5). In light of these, it could be a viable option to allow the energy suppliers or the public authority to bid the capacity of projects supported under their regulatory programmes and channel the funding to strengthen their efforts in incentivising electric EE. This, of course, assumes that the load forecast or capacity procurement target has not already reflected the impacts of those projects on the capacity demand.

- **A savings-based approach to provide incentives is valuable for its flexibility to fit with diverse projects needs and characteristics of customers.** It can support innovative project designs and has the potential of responding readily to changes in the EE market. Most importantly, its flexibility can help capture customised EE opportunities, which the traditional prescriptive schemes may find difficult to accommodate. While the EDR Pilot focuses on peak savings, a savings-based scheme can base incentive on either energy- or peak-savings, or a combination of both, that can be verified according to industry standards. As shown by the example of Standard Offer schemes in the U.S. (Chapter 5), the savings-based approach can be applied in various market and regulatory conditions. But due to the need of efficient operation and complex participation and M&V rules, its application may be limited to non-residential customers and in many cases, customised projects or those above a certain size. While it is essential that participation be streamlined based on a balanced consideration of project risk and scheme coverage, the savings-based approach is not a *'panacea'* to capture all electric EE opportunities. Alternative schemes of prescriptive incentives may well be more appropriate to smaller organisations and residential customers. This underscores the necessity of appropriately designing scheme to reflect unique conditions or barriers for electric EE investment for specific customer or market segments, as opposed to attempting to institute a scheme and hoping that it is able to capture opportunities in *all* customer or market segments.

- **Financial incentives work with other policy instruments to help address barriers for electric EE improvement and achieve policy objectives.** As discussed in Chapter 2, schemes of financial incentive rarely work in isolation and it is more appropriate to view them as part of a toolbox for achieving policy outcomes. This thesis highlights that while a financial incentive is vital, other non-incentive-based policy interventions may also play key roles. As shown in the case study of EDR Pilot (Chapter 6), in the residential sector, depending on how financial incentive schemes are deployed and designed, non-incentive provisions are indispensable including the market transformation programme for efficient products or equipment, financing support for upfront costs, development of supply chains and energy service markets, and behavioural changes. Moreover, as discussed in Chapter 5, it may not be optimal to only use financial incentive and its structure to achieve various policy goals. Besides the general objective of supporting electric EE investment, financial incentives can be structured to promote other objectives, like capturing opportunities from diverse end-use categories and comprehensive projects and increasing savings of non-lighting measures. However, it is important to be realistic about the extent to which a 'deliberately-designed' incentive structure (e.g. stronger incentives for certain end-use or project types) can help capture 'deeper and wider' savings, without overcomplicating the scheme design and creating unnecessary barriers for participation. In a way, it implies a balanced consideration of whether a specific incentive structure would be effective in promoting 'deeper and wider' energy savings, how it would affect outcomes of the incentive scheme and whether other non-incentive-based intervention is going to be more effective – in the case of comprehensive projects, there is evidence that non-incentive support like financing assistance and technical assistance is equally, if not more, valuable.

- **Development of the energy service industry can support savings-based incentive schemes.** As seen in Chapters 5 and 6, a savings-based approach, particularly if it is based on peak savings, tends to have a higher requirement of project sponsors in terms of their staff time, resources and expertise with M&V and project management. Apart from large organisations that are more likely to have dedicated resources, many organisations may need to seek external support, e.g. from third-party ESCos. As seen in North America, ESCos are already providing support to customers (e.g. technical or financing assistance) and scheme administers (e.g. technical review, quality control, marketing and customer engagement, particularly as a ‘champion’ for comprehensive projects). It is vital that the ESCo industry has technical, commercial and M&V expertise with incentive schemes using a savings-based approach as well as projects that are more suitable for the savings-based approach (e.g. larger projects involving customised measures). Following practices of some schemes, dedicated training or a list of partner/approved ESCos may be provided to develop the industry’s capability and expertise. Finally, another important area is the business model of aggregation that could potentially be adopted by ESCos (e.g. market size, profitability level, customer offerings and contractual arrangements, financing) to help pool resources and spread some fixed costs (e.g. M&V, application) to achieve the economy of scale.

- **If a forward capacity market is created to ensure resource adequacy, it is valuable to allow EE as well as DSR to offer as capacity resources.** The main rationale is that EE and DSR capacity tends to come from different electric end-use measures, suggesting the value of allowing them both to bid in capacity auctions to maximise the contribution of demand-side resources. Given the difference in how EE and DSR deliver capacity value, appropriate capacity products need to be defined to reflect their contribution to the resource adequacy as well as resources’ market potential. A robust M&V regime should be put in place for verifying peak savings. It is also of priority to remove barriers for demand-side resources to participate and strengthen the market capability in managing risks of unstable funding and forward planning.

8.3. Future research areas

There are several areas where further research is valuable.

- **Relationship of peak- and energy savings.** Empirical knowledge of the relationship of peak- and energy-saving of electric EE, *specific to the region of interest*, is necessary for using EE as a capacity resource. In regions with more ambitious energy efficiency targets, understanding how these prospective energy savings would translate into peak savings and system peak demand should form a key part of the system planning exercise. While this thesis undertook a comprehensive review, it does observe a wide variance among individual measure types in the same broad category, and between geographies. It highlights the diversity of electricity-using patterns and more importantly, the necessity of developing and maintaining reliable profiles of peak demand impacts of common EE measures through regular load research. Although this thesis focuses on the peak demand of the whole system, it is also useful to develop a rich evidence base on how EE affects the peak load of distribution network, especially if electric EE is deployed to address the network congestion issue that could emerge from wide uptake of solar photovoltaics and electric vehicles.

- **Mechanisms of policy schemes and their interactions.** More research on the design of intervention schemes has practical value. There are at least two dimensions. First, the design features and associated programme mechanisms have direct implications for the effectiveness and outcomes of intervention schemes. After this thesis shows the value of a savings-based approach, further research should focus on detailed case studies on how specific design features would facilitate optimal scheme performance and best practices for scheme implementation. A theory-based policy evaluation is useful – assessment of the assumed logic and mechanisms as embedded in the design features, with primary and secondary evidence, is central to the evaluation and improvement of schemes. Once the use of theory-based evaluation is broadened in different countries, it is helpful to conduct cross-scheme research to synthesise ‘best-practice’ design features for a given type of intervention scheme. Second, another valuable area is the interaction of various schemes. As shown in preceding chapters, the success of financial incentive schemes may depend on the offerings of non-financial incentive schemes (e.g. technical assistance, information) and the relative attractiveness against other financial schemes (e.g. comparative offers). The mechanism of allowing electric EE to offer in the forward capacity market and obtain financial rewards is one example. Further research should focus on how to construct a policy mix to promote electricity use reduction in the most effective and efficient way, in particular how opening electricity market to demand-side resources would imply for the role of other incentive schemes.

- **Potential of feed-in tariff for electricity use reduction.** Specific to the UK policy, while this thesis argues that a scheme modelled after the forward capacity market may play only a minor role in incentivising electric EE, it shows the benefit of a savings-based approach. In a broad sense, it is like a feed-in tariff for electricity use reduction (i.e. kWh) proposed by other scholars and considered in a consultation (Chapter 1). So, the potential of a feed-in tariff for electricity use reduction should be examined. In fact, based on the findings in this thesis, it may deliver a better outcome in driving electric EE investment by focusing on kWh savings that well align with the customer project payback. While energy savings still need to be verified in accordance with M&V protocols, there is flexibility to design the feed-in tariff for electricity use reduction to give strong incentive and appropriate lead time for electric EE projects, without being constrained by the strict rules of the forward capacity market. However, further research is needed to ascertain whether such a scheme would succeed in practice and to understand the enabling conditions.

- **Integration of demand-side resources in the restructured markets.** Progress has been made to integrate DSR in energy, ancillary and capacity markets in some places, although there is an ongoing debate on how it should be treated. In comparison, integrating EE into the wholesale market is still a new area. This thesis focuses on the participation of EE in the forward capacity market and more research can be done for other types of capacity mechanisms. Moreover, EE has not been integrated in the wholesale energy market, even if it is conceptually possible (Chapter 2) – research in this area may make original contributions to the design of electricity markets, especially the extent to which electricity use reduction can be a market commodity. Another area for future research is the business models (e.g. aggregation, planning and risk) that would support the development of EE resource and bidding it in the forward capacity market. This thesis highlights risks like unstable funding and forward planning, and how the private market (e.g. energy service sector) should and can develop relevant capabilities remain an under-explored area.

- **Relationship of EE and DSR.** A deep knowledge of the relationship of EE and DSR is valuable. There are at least two dimensions. First, while there is already some recognition of how peak savings from EE or better insulation could affect DSR (Section 7.6), it is useful to quantify such potential impacts over a more granular time frame. This will help not just system planning, but also the market potential assessment for the development of EE and DSR. In the system with a high penetration of intermittent renewables, for end-uses suitable for DSR, the impact of EE measures on these end-uses can influence their potential in providing flexibility to the system operation. Second, as seen in PJM, capacity resources of EE and DSR mainly come from different customer and end-use categories (Chapter 7). Although it may reflect the technical aspects of electricity use, economics of customer recruitment and metering infrastructure, and the regulatory focus of utility EE programmes may also play a part. However, this may change due to the smart metering rollout and efforts to capture EE opportunities in non-residential sectors. Therefore, if potential EE and DSR resources can be found in the same customer, how the business and operational models should be developed to capture synergies (e.g. cost reduction in marketing, opportunities for cross-sale) is also a promising research area.

- **Capacity adequacy in a decentralised electricity system.** Capacity markets or other capacity mechanisms are designed to ensure resource adequacy in the restructured market that serves a centralised system. Following the proliferation of decentralised generation and storage, future research needs to address issues like how such decentralised capacity should be treated in the capacity market or the centralised market, how to ensure adequate resources in decentralised systems in terms of business and institutional models, and how electricity use reduction and other demand-side resources should be integrated to support the reliability of decentralised systems.

- **Capacity adequacy and flexibility.** As discussed in Chapter 2, in a system with a high share of intermittent renewables, it is critical that resources are adequate and flexible. As the capacity markets are originally designed to ensure adequacy, future research is needed on how it should be adjusted to procure adequate flexible resources – while the wholesale energy market reforms are central, this question becomes important if a decision is taken to set up a capacity market due to practical concerns.

8.4. Contributions of thesis

While the contributions of each paper are discussed in previous chapters, the contribution of this thesis can be seen in three major areas:

- **It broadens the scope of inquiry of how electric EE can be incentivised by market-based mechanisms.** The existing literature focuses on the *EE market created under a regulatory framework* largely outside electricity markets, and market-based instruments used in that context (e.g. trading, auctions or subcontracting to third party organisations). Examples include utility EE obligation programme, which may involve 'white certificate' trading and delivery through third party organisations (e.g. ESCos), and proposals for feed-in tariffs for electricity use reduction. These provisions are typically results of regulatory deliberation and set budgets for allocation and/or targets for energy- and/or peak-savings, which are made financially possible with public funding or energy bill levies. However, this thesis explores a different type of market-based mechanism, i.e. direct integration in the organised electricity markets. It examines the novel idea of relying on a commodity market for trading capacity product as a primary vehicle for providing financial incentives to electric EE. In this case, the EE market and available funding to support EE investment is an outcome of supply-demand dynamics in capacity auctions, not regulatory provisions. By showing that the forward capacity market may only play a minor role in incentivising electric EE, this thesis contributes to the knowledge of the relationship of regulatory provisions and electricity markets in driving electric EE, particularly the importance of the former.

- **This thesis contributes to the literature on the design of financial incentive schemes for promoting electric EE, which is so far limited.** A comprehensive analysis of peak- and energy-savings suggests drawbacks of the approach of basing financial incentives exclusively on peak-savings. It starts to fill the gap of literature of how the relationship of peak- and energy-savings differs by season, measure type and customer sector, which is key to the design, operation and evaluation of EE schemes. Moreover, by examining experiences in North America, Europe and the EDR Pilot in the UK, this thesis contributes to the understanding of the role and benefits of a savings-based approach for providing financial incentives to support electric EE. It fills the gap of *what* the benefits are of a savings-based approach and *for whom*, and *how* these benefits may materialise in practice. These studies are first of their kind in examining the value and limitation of an incentive scheme modelled after the forward capacity market in driving electric EE.

- **This thesis deepens the knowledge of how a forward capacity market can promote demand-side resources as capacity resources.** By examining the process and outcome of procuring demand-side resources in the forward capacity auctions of PJM, ISO-NE and GB Capacity Market, it provides empirical analysis of their nature, scale and drivers of participation, highlighting the difference of EE and DSR. Such knowledge can inform the design of integration mechanisms and assess whether supportive policies would be needed to promote the contribution of demand-side resources.

9 | References

Adib, P., Schubert, E., Oren, S., 2008. Chapter 9 - Resource Adequacy: Alternate Perspectives and Divergent Paths A2 - Sioshansi, Fereidoon P, Competitive Electricity Markets. Elsevier, Oxford, pp. 327-362.

Adib, P., Zarnikau, J., Baldick, R., 2013. Chapter 10 - Texas Electricity Market: Getting Better A2 - Sioshansi, Fereidoon P, Evolution of Global Electricity Markets. Academic Press, Boston, pp. 265-296.

AID-EE, 2006. Guidelines for the monitoring, evaluation and design of energy efficiency policies: How policy theory can guide monitoring & evaluation efforts and support the design of SMART policies. Active Implementation of the European Directive on Energy Efficiency (AID-EE).

Amann, J.T., Mendelsohn, E., 2005. Comprehensive Commercial Retrofit Programs: A Review of Activity and Opportunities. American Council for an Energy-Efficient Economy.

Anthony, A., Foley, L., 2014. Energy Efficiency in Rhode Island's System Reliability Planning, The 2014 ACEEE Summer Study on Energy Efficiency in Buildings.

Aunedi, M., Kountouriotis, P.A., Calderon, J.E.O., Angeli, D., Strbac, G., 2013. Economic and Environmental Benefits of Dynamic Demand in Providing Frequency Regulation. IEEE Transactions on Smart Grid 4, 2036-2048.

Axon, C.J., Bright, S.J., Dixon, T.J., Janda, K.B., Kolokotroni, M., 2012. Building communities: Reducing energy use in tenanted commercial property. Building Research and Information 40, 461-472.

Ayres, L., 2008. Semi-Structured Interview, in: Given, L.M. (Ed.), The SAGE Encyclopedia of Qualitative Research Methods. SAGE Publications, Inc., Thousand Oaks.

Baker, P., Hogan, M., 2014. Policy Brief: A Critique of the UK's Capacity Market Proposals. Regulatory Assistance Project.

Barbose, G., Goldman, C., Hoffman, I., Billingsley, M., 2013. The Future of Utility Customer-Funded Energy Efficiency Programs in the United States: Projected Spending and Savings to 2025. Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, California.

BC Hydro, 2009. F2009 Demand Side Management Milestone Evaluation Summary Report. BC Hydro.

BC Hydro, 2014. Demand Side Management Milestone Evaluation Summary Report F2013. BC Hydro. Report submitted to the British Columbia Utilities Commission.

BEIS, 2016a. Digest of United Kingdom Energy Statistics (DUKES), in: Department of Business, E.a.I.S. (Ed.).

BEIS, 2016b. Energy Consumption in the UK. November 2016. Department for Business, Energy & Industrial Strategy.

BEIS, 2017a. Electricity Demand Reduction Pilot. Interim Evaluation Findings. Department for Business, Energy & Industrial Strategy, London, United Kingdom.

BEIS, 2017b. Household Energy Efficiency National Statistics, headline release January 2017, Department for Business, Energy and Industrial Strategy.

Benedettini, S., 2013. PJM and ISO-NE forward capacity markets: a critical assessment. Centre for Research on Energy and Environmental Economics and Policy.

Bertoldi, P., Rezessy, S., 2007. A step into the unknown: feed-in tariff for energy saving, ECEEE 2007 Summer Study. European Council for Energy Efficient Economy.

Bertoldi, P., Rezessy, S., Lees, E., Baudry, P., Jeandel, A., Labanca, N., 2010. Energy supplier obligations and white certificate schemes: Comparative analysis of experiences in the European Union. Energy Policy 38, 1455-1469.

Bertoldi, P., Rezessy, S., Oikonomou, V., 2013. Rewarding energy savings rather than energy efficiency: Exploring the concept of a feed-in tariff for energy savings. Energy Policy 56, 526-535.

Bertoldi, P., Rezessy, S., Oikonomou, V., Boza-Kiss, B., 2009. Feed-in tariff for energy saving: thinking of the design, ECEEE 2009 Summer Study. European Council for an Energy Efficient Economy.

Bilton, M., Woolf, M., Djapic, P., Aunedi, M., Carmichael, R., Strbac, G., 2014. Impact of energy efficient appliances on network utilisation. Report C2 for the Low Carbon London LCNF Project: Imperial College London, 2014.

Bingham, P., 2015. SBR & DSBR Market Update Winter 2015/16: Results of Tender Round 2. National Grid.

Birckmayer, J.D., Weiss, C.H., 2000. Theory-Based Evaluation in Practice. Evaluation Review 24, 407-431.

Blatter, J.K., 2008. Case Study, in: Given, L.M. (Ed.), The SAGE Encyclopedia of Qualitative Research Methods. SAGE Publications, Inc., Thousand Oaks.

Blumstein, C., Krieg, B., Schipper, L., York, C., 1980. Overcoming social and institutional barriers to energy conservation. Energy 5, 355-371.

Blyth, W., Gross, R., Speirs, J., Sorrell, S., Nicholls, J., Dorgan, A., Hughes, N., 2014. Low carbon jobs: The evidence for net job creation from policy support for energy efficiency and renewable energy. UK Energy Research Centre (UKERC) Technology & Policy Assessment Function.

Boardman, B., 2004a. Achieving energy efficiency through product policy: the UK experience. Environmental Science & Policy 7, 165-176.

Boardman, B., 2004b. New directions for household energy efficiency: evidence from the UK. Energy Policy 32, 1921-1933.

Boardman, B., 2012a. Achieving Zero: Delivering Future-Friendly Buildings. Environmental Change Institute, University of Oxford, Oxford, United Kingdom.

Boardman, B., 2012b. Fuel poverty synthesis: Lessons learnt, actions needed. Energy Policy 49, 143-148.

Boardman, B., 2014. Low-energy lights will keep the lights on. Carbon Management 5, 361-371.

Bonbright, J.C., 1961. Principles of public utility rates. Columbia University Press.

Boßmann, T., Elsland, R., Lickert, F., Wietschel, M., 2013. The German load curve in 2050: structural changes through energy efficiency measures and their impacts on the electricity supply side, ECEEE 2013 Summer Study - Rethink, Renew, Restart.

Bowring, J., 2013a. Capacity Markets in PJM. Economics of Energy & Environmental Policy 2.

Bowring, J.E., 2008. Chapter 10 - The Evolution of PJM's Capacity Market A2 - Sioshansi, Fereidoon P, Competitive Electricity Markets. Elsevier, Oxford, pp. 363-386.

Bowring, J.E., 2013b. Chapter 9 - The Evolution of the PJM Capacity Market: Does It Address the Revenue Sufficiency Problem? A2 - Sioshansi, Fereidoon P, Evolution of Global Electricity Markets. Academic Press, Boston, pp. 227-264.

Bradley, P., Leach, M., Torriti, J., 2013. A review of the costs and benefits of demand response for electricity in the UK. Energy Policy 52, 312-327.

Brattle Group, Sustainability First, 2012. GB Electricity Demand - 2010 and 2025. Initial Brattle Electricity Demand-Side Model - Scope for Demand Reduction and Flexible Response. Sustainability First.

Breyer, S., 1998. Typical justifications for regulation, in: Baldwin, R., Scott, C., Hood, C. (Eds.), A Reader on Regulation. Oxford University Press, Oxford; New York, pp. 59-92.

Brinkmann, S., 2008. Interviewing, in: Given, L.M. (Ed.), The SAGE Encyclopedia of Qualitative Research Methods. SAGE Publications, Inc., Thousand Oaks.

Brown, M., 2015. Innovative energy-efficiency policies: an international review. Wiley Interdisciplinary Reviews: Energy and Environment 4, 1-25.

Bushnell, J.B., Mansur, E.T., Saravia, C., 2008. Vertical arrangements, market structure, and competition: An analysis of restructured US electricity markets. The American Economic Review 98, 237-266.

Bushnell, J.B., Wolfram, C., 2005. Ownership Change, Incentives and Plant Efficiency: The Divestiture of U.S. Electric Generation Plants.

Cadmus, 2009. Connecticut Small Business Energy Advantage Impact Evaluation Report Program Year 2007. Prepared for Connecticut Energy Conservation Management Board, the Connecticut Light & Power Company and the United Illuminating Company.

CADMUS, 2010a. PacifiCorp Energy FinAnswer 2005-2008 Utah Program Evaluation. Prepared for PacifiCorp.

CADMUS, 2010b. PacifiCorp Energy FinAnswer 2008 Idaho Program Evaluation. Prepared for PacifiCorp.

Cadmus, 2010c. PacifiCorp Energy FinAnswer Washington Program Evaluation 2005-2008. Prepared for PacifiCorp.

Cadmus, 2012. Efficiency Maine Trust Residential Lighting Program Evaluation: Final Report. The Cadmus Group Inc. Prepared for Efficiency Maine Trust.

Caird, S., Roy, R., Potter, S., 2012. Domestic heat pumps in the UK: user behaviour, satisfaction and performance. Energy Efficiency 5, 283-301.

CAISO, 2013. Demand Response and Energy Efficiency Roadmap: Maximizing Preferred Resources. California ISO, Folsom, California.

Capon, C., 2004. Understanding organisational context: Inside and outside organisations. Pearson Education.

Cappers, P., Goldman, C., Kathan, D., 2010. Demand response in U.S. electricity markets: Empirical evidence. Energy 35, 1526-1535.

Cappers, P., MacDonald, J., Goldman, C., Ma, O., 2013. An assessment of market and policy barriers for demand response providing ancillary services in U.S. electricity markets. Energy Policy 62, 1031-1039.

Cary, R., Benton, D., 2012. Creating a market for electricity savings: Payng for energy efficiency through the Energy Bill. Green Alliance.

Cebon, P.B., 1992. 'Twixt cup and lip organizational behaviour, technical prediction and conservation practice. Energy Policy 20, 802-814.

CEC, 2013. 2013 Integrated Energy Policy Report. California Energy Commission.

Centolella, P., 2010. The integration of Price Responsive Demand into Regional Transmission Organization (RTO) wholesale power markets and system operations. Energy 35, 1568-1574.

Chao, H.-P., Oren, S., Wilson, R., 2008. Reevaluation of Vertical Integration and Unbundling in Restructured Electricity Markets, in: Sioshansi, F.P. (Ed.), Competitive Electricity Markets: Design, implementation, performance. Elsevier, Oxford, UK, pp. 27-64.

CLC, 2011. Annual Report on Energy Efficiency Activities in 2010. Cape Light Compact.

CLC, 2012. Annual Report on Energy Efficiency Activities in 2011. Cape Light Compact.

CLC, 2013. Annual Report on Energy Efficiency Activities in 2012. Cape Light Compact.

CMA, 2016. Energy market investigation - Summary of final report. Competition and Markets Authority.

CorreljÉ, A.F., De Vries, L.J., 2008. Chapter 2 - Hybrid Electricity Markets: The Problem of Explaining Different Patterns of Restructuring A2 - Sioshansi, Fereidoon P, Competitive Electricity Markets. Elsevier, Oxford, pp. 65-93.

Cowart, R., Neme, C., 2013. Can Competition Accelerate Energy Savings? Options and Challenges for Efficiency Feed-in Tariffs. Energy & Environment 24, 57-81.

CPUC, 2006. California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals. State of California Public Utilities Commission.

CPUC, 2010a. 2006-2008 Energy Efficiency Evaluation Report. California Public Utilities Commission.

CPUC, 2010b. Transmittal Letter for the 2010-2012 Energy Efficiency Evaluation, Measurement and Verification Work Plan.

Craig, C.S., McCann, J.M., 1978. Assessing Communication Effects on Energy Conservation. Journal of Consumer Research 5, 82-88.

Cramton, P., Ockenfels, A., Stoft, S., 2013. Capacity Market Fundamentals. Economics of Energy & Environmental Policy 2.

Cramton, P., Stoft, S., 2005. A capacity market that makes sense, IEEE Power Engineering Society General Meeting, 2005, pp. 3022-3034.

Cramton, P., Stoft, S., 2006. The convergence of market designs for adequate generating capacity.

Crew, M.A., 1991. Introduction to competition and the regulation of utilities, in: Crew, M.A. (Ed.), Competition and the Regulation of Utilities. Kluwer Academic Publishers, Dordrecht, pp. 1-6.

Darby, S., 2010a. Literature review for the Energy Demand Research Project. Environmental Change Institute, University of Oxford and Ofgem (Office of Gas and Electricity Markets), London.

Darby, S., 2010b. Smart metering: what potential for householder engagement? Building Research & Information 38, 442-457.

Darby, S., Liddell, C., Hills, D., Drabble, D., 2015. Smart Metering Early Learning Project: Synthesis report. Research conducted for DECC by the Environmental Change Institute, Oxford, the University of Ulster and the Tavistock Institute. Department Energy and Climate Change.

Darby, S., Strömbäck, J., Wilks, M., 2013. Potential carbon impacts of smart grid development in six European countries. Energy Efficiency 6, 725-739.

Darby, S.J., McKenna, E., 2012. Social implications of residential demand response in cool temperate climates. Energy Policy 49, 759-769.

DCLG, 2011. Private Landlords Survey 2010. Department for Communities and Local Government, London.

DCLG, 2015. Social Housing Lettings: April 2014 to March 2015, England. Department for Communities and Local Government.

DCLG, 2016a. English housing survey 2014 to 2015: housing stock report. Department for Communities and Local Government, London.

DCLG, 2016b. English Housing Survey - Energy Report, 2014. Department for Communities and Local Government.

DCLG, 2016c. English housing survey headline report 2014 to 2015. Department for Communities and Local Government, London.

DCLG, 2017. Local Authority Housing Data. Table 100: number of dwellings by tenure and district, England (as of April 2015), in: Government, D.o.C.a.L.a. (Ed.).

de la Rue du Can, S., Leventis, G., Phadke, A., Gopal, A., 2014. Design of incentive programs for accelerating penetration of energy-efficient appliances. Energy Policy 72, 56-66.

DeCanio, S.J., 1993. Barriers within firms to energy-efficient investments. Energy Policy 21, 906-914.

DeCanio, S.J., 1998. The efficiency gap: bureaucratic and organisational barriers to profitable energy saving investments. Energy Policy 26, 441-454.

DECC, 2012. Electricity Demand Reduction: Consultation on options to encourage permanent reductions in electricity use. Department of Energy and Climate Change.

DECC, 2013a. Consultation on options to reduce electricity demand - Government Response. Department of Energy and Climate Change.

DECC, 2013b. Impact Assessment (IA) for Electricity Demand Reduction - Amendment to Capacity Market Clauses.

DECC, 2014a. Electricity Demand Reduction Pilot Scheme: Participant Handbook. Department of Energy and Climate Change.

DECC, 2014b. Electricity Demand Reduction Pilot: Measurement and Verification Manual. Department of Energy and Climate Change.

DECC, 2014c. Evaluation of the Carbon Emissions Reduction Target and Community Energy Saving Programme. Research undertaken for DECC by Ipsos MORI, CAG Consultants, UCL and Energy Saving Trust. Department of Energy and Climate Change, London.

DECC, 2014d. Implementing Electricity Market Reform (EMR): Finalised policy positions for implementation of EMR. Department of Energy and Climate Change.

DECC, 2015a. Electricity Demand Reduction Pilot Scheme Phase II - Participant Handbook. Department of Energy and Climate Change, London.

DECC, 2015b. Evaluation of the Renewable Heat Premium Payment Scheme Phase Two. Department of Energy and Climate Change.

DECC, 2015c. The participation of non-generation activities in the GB Capacity Market.

DECC, 2015d. Successful bidders in EDR Pilot Auction 29 January 2015. Department of Energy and Climate Change.

DECC, 2016a. Final UK greenhouse gas emissions national statistics: 1990-2014. Department of Energy and Climate Change.

DECC, 2016b. Government Response to the March 2016 consultation on further reforms to the Capacity Market.

DECC, 2016c. Successful bidders in EDR phase II auction. Department of Energy and Climate Change.

Defeuilley, C., 2009. Retail competition in electricity markets. Energy Policy 37, 377-386.

Domah, P., Pollitt, M.G., 2001. The restructuring and privatisation of the electricity distribution and supply businesses in England and Wales: a social cost-benefit analysis. Fiscal Studies 22, 107-146.

Doris, E., Cochran, J., Vorum, M., 2009. Energy Efficiency Policy in the United States: Overview of Trends at Different Levels of Government. National Renewable Energy Laboratory.

Downs, A., Chittum, A., Hayes, S., Neubauer, M., Nowak, S., Vaidyanathan, S., Farley, K., Cui, C., 2013. The 2013 State Energy Efficiency Scorecard. American Council for an Energy-Efficient Economy.

Downs, A., Cui, C., 2014. Energy Efficiency Resource Standards: A New Progress Report on State Experience. American Council for an Energy-Efficient Economy, Washington, DC.

DPS, 2009a. Report to the Public Service Board: 2006-2008 Evaluation Activities Related to Vermont's Statewide Energy Efficiency Utility. Vermont Department of Public Service.

DPS, 2009b. Vermont Department of Public Service Electric Energy Efficiency Evaluation Plan 2009-2011. Vermont Department of Public Service.

DPS, 2011. Vermont Department of Public Service Electric Energy Efficiency Evaluation Plan 2012-2014. Vermont Department of Public Service.

DSIRE, 2016. Database of State Incentives for Renewables & Efficiency in: Clean Energy Technology Center, N.C.S.U. (Ed.).

EC, 2013. Guidance note on Directive 2012/27/EU on energy efficiency, amending Directives 2009/125/EC and 2010/30/EC, and reporting Directives 2004/8/EC and 2006/32/EC. Ariticle 7: Energy efficiency obligation schemes. The European Commission.

EC, 2016a. Commission Staff Working Document Accompanying the document Report from the Commission Final Report of the Sector Inquiry on Capacity Mechanisms. European Commission.

EC, 2016b. Final Report of the Sector Inquiry on Capacity Mechanisms. European Commission.

ECEEE, 2013. Understanding the Energy Efficiency Directive - Steering through the maze #6: A guide from eceee. European Council for an Energy Efficient Economy.

ECONOLER, Cadmus, 2015. 2014 Evaluation of Industrial Energy Efficiency Programs. Prepared for Independent Electricity System Operator.

EIA, 2016. Monthly Energy Review. Carbon Dioxide emissions from energy consumption. U.S. Energy Information Administration.

Element Energy, 2012. Demand Side Response in the Non-Domestic Sector. Prepared for Ofgem.

Elsharkawy, H., Rutherford, P., 2015. Retrofitting social housing in the UK: Home energy use and performance in a pre-Community Energy Saving Programme (CESP). Energy and Buildings 88, 25-33.

EST, 2011. Lit up: an LED lighting field trial. The Energy Saving Trust.

Eto, J., 1996. The Past, Present and Future of U.S. Utility Demand-Side Management Programs. Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory, University of Berkeley, Berkeley, California.

Evergreen Economics, 2014. Evaluation of the Hawaii Energy Conservation and Efficiency Programs: Program Year 2012. Evergreen Economics. Prepared for the State of Hawaii Public Utilities Commission.

Eyre, N., 1997. Barriers to Energy Efficiency: More Than Just Market Failure. Energy & Environment 8, 25-43.

Eyre, N., 2013a. Energy saving in energy market reform—The feed-in tariffs option. Energy Policy 52, 190-198.

Eyre, N., 2013b. Review of technical potential for electricity demand reduction. Environmental Change Institute, University of Oxford and Department of Energy and Climate Change.

Eyre, N., Baruah, P., 2015. Uncertainties in future energy demand in UK residential heating. Energy Policy 87, 641-653.

Eyre, N., Fawcett, T., Spyridaki, N.-A., Oikonomou, V., Tourkolias, C., Barbero, J., 2015. Energy Saving Policies and Energy Efficiency Obligation Scheme. ENSPOL Energy Saving Policies.

Fabrizio, K.R., Rose, N.L., Wolfram, C.D., 2007. Do markets reduce costs? Assessing the impact of regulatory restructuring on US electric generation efficiency. The American Economic Review 97, 1250-1277.

Faruqui, A., George, S.S., 2002. The Value of Dynamic Pricing in Mass Markets. The Electricity Journal 15, 45-55.

Faruqui, A., Hajos, A., Hledik, R.M., Newell, S.A., 2010. Fostering economic demand response in the Midwest ISO. Energy 35, 1544-1552.

Fawcett, T., Boardman, B., 2009. Housing market transformation, ECEEE 2009 Summer Study: Act! Innovate! Deliver! Reducing Energy Demand Sustainably. European Council for an Energy Efficient Economy.

FERC, 2006. Assessment of Demand Response and Advanced Metering Staff Report.

FERC, 2008. Assessment of Demand Response and Advanced Metering Staff Report.

FERC, 2009. A National Assessment of Demand Response Potential. Federal Energy Regulatory Commission.

FERC, 2011. Assessment of Demand Response and Advanced Metering Staff Report - February 2011. Federal Energy Regulatory Commission.

FERC, 2012. Assessment of Demand Response & Advanced Metering Staff Report - December 2012. Federal Energy Regulatory Commission.

FERC, 2013a. Centralized Capacity Market Design Elements. Commission Staff Report AD13-7-000.

FERC, 2013b. Order on proposed tariff revisions. Docket No. ER12-1627-000.

FERC, 2016. Order on Complaint. Docket No. EL14-20-000.

Finon, D., Pignon, V., 2008. Electricity and long-term capacity adequacy: The quest for regulatory mechanism compatible with electricity market. Utilities Policy 16, 143-158.

Foster, B., Chittum, A., Hayes, S., Neubauer, M., Nowak, S., Vaidyanathan, S., Farley, K., Schultz, K., Sullivan, T., Sheppard, C., Jacobson, A., Chamberlin, C., Mugica, Y., 2012. The 2012 State Energy Efficiency Scorecard. American Council for an Energy-Efficient Economy.

Franconi, E., 2016. Next-Genertion Utility Programs: How M&V 2.0 is Enabling a "Negawatt" Market. Rocky Mountain Institute.

Franconi, E., Gee, M., Goldberg, M., Granderson, J., Guiterman, T., Li, M., Smith, B.A., 2017. The Status and Promise of Advanced M&V: An Overview of "M&V 2.0" Methods, Tools, and Applications. Rocky Mountain Institute, University of Chicago, DNV-GL, Lawrence Berkeley National Laboratory, EnergySavvy, U.S. Department of Energy, Pacific Gas and Electric.

Furrey, L., Black, S., 2009. Energy Efficiency Resource Standards: A State Model. American Council for an Energy-Efficient Economy, Washington, D.C.

Gaspar, R., Antunes, D., 2011. Energy efficiency and appliance purchases in Europe: Consumer profiles and choice determinants. Energy Policy 39, 7335-7346.

Gavin, C., 2014. Special feature - Seasonal variations in electricity demand, UK Energy Statistics 2014 Edition. Department of Energy and Climate Change.

GDS Associates, Navigant, 2012. Industrial and process Efficiency Program Market Characterization and Market Assessment Evaluation. Prepared for New York State Energy Research and Development Authority.

Geller, H., Attali, S., 2005. The Experience with Energy Efficiency Policies and Programmes in IEA Countries. International Energy Agency.

Geller, H., Nadel, S., 1994. Market transformation strategies to promote end-use efficiency. Annual Review of Energy and the Environment 19, 301-346.

GfK, 2016. Energy Efficiency: the Rise of the 'A' Team in Domestic Appliances. GfK.

Gifford, S., 1994. A Review of Milgrom and Roberts'sEconomics, Organization and Management. Journal of Economics & Management Strategy 3, 407-436.

Gilleo, A., 2014. Picking All the Fruit: All Cost-Effective Energy Efficiency Mandates, 2014 ACEEE Summer Study on Energy Efficiency in Buildings. American Council for an Energy-Efficient Economy.

Gilleo, A., Chittum, A., Farley, K., Neubauer, M., Nowak, S., Ribeiro, D., Vaidyanathan, S., 2014. The 2014 State Energy Efficiency Scorecard. American Council for an Energy-Efficient Economy.

Gilleo, A., Nowak, S., Kelly, M., Vaidyanathan, S., Shoemaker, M., Chittum, A., Bailey, T., 2015a. The 2015 State Energy Efficiency Scorecard. American Council for an Energy-Efficient Economy, Washington, DC.

Gilleo, A., Nowak, S., Kelly, M., Vaidyanathan, S., Shoemaker, M., Chittum, A., Beiley, T., 2015b. The 2015 State Energy Efficiency Scorecard. American Council for an Energy-Efficient Economy.

Gillingham, K., Kotchen, M.J., Rapson, D.S., Wagner, G., 2013. Energy policy: The rebound effect is overplayed. Nature 493, 475-476.

Glazer, C., 2014. Demand Response in PJM: Past Successes and the Murky Legal Future of Demand Response... PJM.

Goldman, C., Hirst, E., Krause, L., 1989. Least-Cost Planning in the Utility Sector: Progress and Challenges. Lawrence Berkeley Laboratory and Oak Ridge National Laboratory.

Goldman, C., Reid, M., Levy, R., Silverstein, A., 2010. Coordination of Energy Efficiency and Demand Response. Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory.

Golove, W.H., Eto, J.H., 1996. Market Barriers to Energy Efficiency: A Critical Reappraisal of the Rationale for Public Policies to Promote Energy Efficiency. Energy & Environment Division, Lawrence Berkeley National Laboratory, University of Berkeley, Berkeley, California.

Gottstein, M., Schwartz, L., 2010. The Role of Forward Capacity Markets in Increasing Demand-Side and Other Low-Carbon Resources: Experience and Prospects. The Regulatory Assistance Project.

Gottstein, M., Skillings, S.A., 2012. Beyond capacity markets — Delivering capability resources to Europe's decarbonised power system, 2012 9th International Conference on the European Energy Market, pp. 1-8.

Graham, C., 1998. Is there a crisis in regulatory accountability?, in: Baldwin, R., Scott, C., Hood, C. (Eds.), A Reader on Regulation. Oxford University Press, Oxford; New York.

Green Alliance, 2012. Cutting Britain's energy bill: making the most of product efficiency standards. Green Alliance, London, United Kingdom.

Greening, L., Greene, D.L., Difiglio, C., 2000. Energy efficiency and consumption — the rebound effect — a survey. Energy Policy 28, 389-401.

Greening, L.A., 2010. Demand response resources: Who is responsible for implementation in a deregulated market? Energy 35, 1518-1525.

Grueneich, D.M., 2015. The Next Level of Energy Efficiency: The Five Challenges Ahead. The Electricity Journal 28, 44-56.

Harmelink, M., Nilsson, L., Harmsen, R., 2008. Theory-based policy evaluation of 20 energy efficiency instruments. Energy Efficiency 1, 131-148.

Hattori, T., Tsutsui, M., 2004. Economic impact of regulatory reforms in the electricity supply industry: a panel data analysis for OECD countries. Energy Policy 32, 823-832.

Hausman, J.A., 1979. Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables. The Bell Journal of Economics 10, 33-54.

Hawaii Energy, 2013. Hawaii Energy Efficiency Program Technical Reference Manual (TRM) PY 2013: Measure Savings Calculations. Hawaii Energy.

HCA, 2015. Stastical Data Return (SDR) 2014 to 2015 - Private registered provider social housing stock in England. Homes and Communities Agency.

Hedman, B., Steiner, J., 2013. DSM in the rate case: a regulatory model for resource parity between supply and demand, Public Utilities Fortnightly. Public Utilities Reports, Inc, p. 34.

Hewett, M.J., 1998. Achieving energy efficiency in a restructured electric utility industry. Report prepared for Minnesotans for an Energy Efficient Economy, Centre for Energy & Environment, Minneapolis, MN.

Hilke, A., Ryan, L., 2012. Mobilising investment in energy efficiency. Economic instruments for low-energy buildings. International Energy Agency.

Hirst, E., Brown, M., 1990. Closing the efficiency gap: barriers to the efficient use of energy. Resources, Conservation and Recycling 3, 267-281.

HM Government, 2017. Industrial Strategy - Building a Britain fit for the future.

Hogan, M., 2005. On an 'Energy Only' Electricity Market Design for Resource Adequacy. Center for Business and Government, John F. Kennedy School of Government, Harvard University, Cambridge, Massachusetts.

Hogan, M., 2006. Resource Adequacy Mandates and Scarcity Pricing ("Belts and Suspenders"). John F. Kennedy School of Government, Harvard University.

Hogan, M., 2017. Follow the missing money: Ensuring reliability at least cost to consumers in the transition to a low-carbon power system. The Electricity Journal 30, 55-61.

Hogan, M., O'Boyle, M., Aggarwal, S., 2015. Do pay-for-performance capacity market deliver the grid resiliency outcomes we need? GreenTech Media.

Hogan, W.W., 1992. Contract networks for electric power transmission. Journal of Regulatory Economics 4, 211-242.

Hogan, W.W., 1998. Competitive electricity market design: A wholesale primer.

Hopper, N., Barbose, G., Goldman, C., Schlegel, J., 2009. Energy efficiency as a preferred resource: evidence from utility resource plans in the Western US and Canada. Energy Efficiency 2, 1-16.

Houston, D.A., 1983. Implicit Discount Rates and the Purchase of Untried, Energy-Saving Durable Goods. Journal of Consumer Research 10, 236-246.

Howarth, R.B., Sanstad, A.H., 1995. DISCOUNT RATES AND ENERGY EFFICIENCY. Contemporary Economic Policy 13, 101-109.

Hunt, S., 2002. Making Competition Work in Electricity. Wiley, New York.

Hurley, D., Peterson, P., Whited, M., 2013. Demand Response as a Power System Resource: Program Designs, Performance, and Lessons Learned in the United States. The Regulatory Assistance Project (RAP).

IEA, 2014a. Capturing the Multiple Benefits of Energy Efficiency. International Energy Agency, Paris.

IEA, 2014b. The Power of Transformation: Wind, Sun and the Economics of Flexible Power Systems. International Energy Agency.

IEA, 2015. Energy Efficiency Market Report 2015: Market Trends and Medium-Term Prospects. International Energy Agency.

IEA, 2016a. CO2 Emissions from fuel combustion. International Energy Agency, Paris, France.

IEA, 2016b. World Energy Outlook 2016. International Energy Agency, Paris, France.

IEA, 2017. Market-based Instrument for Energy Efficiency: Policy Choice and Design. International Energy Agency, Paris, France.

IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Group I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

ISO-NE, 2014a. Forward Capacity Auction 2017-2018 Obligations. ISO New England Inc.

ISO-NE, 2014b. ISO New England Manual for Measurement and Verification of Demand Reduction Value from Demand Resources. Manual M-MVDR. Revision: 6. Effective Date: June 1, 2014.

ISO-NE, 2015a. ISO New England's Internal Market Monitor - 2014 Annual Markets Report.

ISO-NE, 2015b. ISO New England Manual for the Forward Capacity Market (FCM) - Manual M-20. ISO New England Inc.

Jaffe, A.B., Stavins, R.N., 1994. The energy-efficiency gap What does it mean? Energy Policy 22, 804-810.

Jamal, M., 2015. Taking the Power Back, Finance & Development. International Monetary Fund.

Jamasb, T., Pollitt, M., 2005. Electricity Market Reform in the European Union: Review of Progress toward Liberalization & Integration. The Energy Journal 26, 11-41.

Jamasb, T., Pollitt, M., 2007. Incentive regulation of electricity distribution networks: Lessons of experience from Britain. Energy Policy 35, 6163-6187.

Janda, K.B., 2014. Building communities and social potential: Between and beyond organizations and individuals in commercial properties. Energy Policy 67, 48-55.

Jenkins, C., Neme, C., Enterline, S., 2011. Energy efficiency as a resource in the ISO New England Forward Capacity Market. Energy Efficiency 4, 31-42.

Johnson, L.L., 1973. Behavior of the Firm Under Regulatory Constraint: A Reassessment. The American Economic Review 63, 90-97.

Joskow, P., 2006a. Introduction, in: Sioshansi, F.P., Pfaffenberger, W. (Eds.), International Experience in Restructured Electricity Markets: What Works, What Does Not, and Why? Elsevier.

Joskow, P.L., 1996. Comments on Power Struggles: Explaining Deregulatory Reforms in Electricity Markets, Brookings Papers on Economic Activity: Microeconomics. The Brookings Institute, pp. 251-264.

Joskow, P.L., 1997. Restructuring, Competition and Regulatory Reform in the U.S. Electricity Sector. The Journal of Economic Perspectives 11, 119-138.

Joskow, P.L., 2003a. The Difficult Transition to Competitive Electricity Markets in the U.S. Center for Energy and Environmental Policy Research.

Joskow, P.L., 2003b. Electricity Sector Restructuring and Competition: Lessons Learned, Working Paper 2003-014. Center for Energy and Environmental Policy Research, Massachusetts Institute of Technology.

Joskow, P.L., 2005. Markets for power in the United States: An interim assessment.

Joskow, P.L., 2006b. Incentive regulation in theory and practice: electricity distribution and transmission networks, Cambridge Working Papers in Economics no. 0607 and Electricity Policy Research Group Working Paper Series no. 0511.

Joskow, P.L., 2007. Competitive electricity markets and investment in new generating capcaity, in: Helm, D. (Ed.), The New Energy Paradigm. Oxford University Press.

Joskow, P.L., 2008a. Capacity payments in imperfect electricity markets: Need and design. Utilities Policy 16, 159-170.

Joskow, P.L., 2008b. Lessons Learned From Electricity Market Liberalization. The Energy Journal.

Joskow, P.L., Rose, N.L., 1985. The Effects of Technological Change, Experience, and Environmental Regulation on the Construction Cost of Coal-Burning Generating Units. The RAND Journal of Economics 16, 1-27.

Joskow, P.L., Schmalensee, R., 1987. The Performance of Coal-Burning Electric Generating Units in the United States: 1960-1980. Journal of Applied Econometrics 2, 85-109.

Julien, H., 2008. Survey Research, in: Given, L.M. (Ed.), The SAGE Encyclopedia of Qualitative Research Methods. SAGE Publications, Inc., Thousand Oaks.

K.McGinn, M., 2008. Secondary Data, in: Given, L.M. (Ed.), The SAGE Encyclopedia of Qualitative Research Methods. SAGE Publications, Inc., Thousand Oaks.

Katsigiannakis, G., Pande, H., Vadakattu, R., Muthiah, S., 2016. Pilgrim Retires, Prices Decline: What Happened in the ISO-NE FCA 10 Auction? ICF International, Inc.

Keech, A., 2015. Energy Efficiency in RPM, in: Market Operations, P. (Ed.). PJM.

Kelly, G., 2012. Sustainability at home: Policy measures for energy-efficient appliances. Renewable and Sustainable Energy Reviews 16, 6851-6860.

KEMA, 2009. National Grid USA 2008 Custom Lighting Impact Evaluation.

Kempton, W., Montgomery, L., 1982. Folk quantification of energy. Energy 7, 817-827.

Khan, J., Harmelink, M., Harmsen, R., Irrek, W., Labanca, N., 2006. Guidelines for the monitoring, evaluation and design of energy efficiency policies - How policy theory can guide monitoring & evaluation efforts and support the design of SMART policies. Ecofys.

Killip, G., 2011. Can market transformation approaches apply to service markets? An investigation of innovation, learning, risk and reward in the case of low-carbon housing refurbishment in the UK, ECEEE 2011 Summer Study Energy Efficiency First: The Foundation of a Low-Carbon Society. European Council for an Energy Efficienct Economy.

Killip, G., 2013. Products, practices and processes: exploring the innovation potential for low-carbon housing refurbishment among small and medium-sized enterprises (SMEs) in the UK construction industry. Energy Policy 62, 522-530.

King, C., Delurey, D., 2005. Efficiency and Demand Response: Twins, Siblings or Cousins? Public Utilities Fortnightly March 2005.

King, R., Crawford, J., Huddleston, B., Isser, S., 2015. The Debate About Demand Response and Wholesale Electricity Markets. The South-Central Partnership for Energy Efficiency as a Resource

Knight, P., Hurley, D., Fields, S., 2014. Energy Efficiency in U.S. Capacity Markets - A Synapse Mini-Paper.

Kushler, M., Nadel, S., York, D., Dietsch, N., Gander, S., 2006. Energy Efficiency Resource Standards: The Next Great Leap Forward?, 2006 ACEEE Summer Study on Energy Efficiency in Buildings.

Kushler, M., Nowak, S., Witte, P., 2012. A National Survey of State Policies and Practices for the Evaluation of Ratepayer-Funded Energy Efficiency Programs. American Council for an Energy-Efficient Economy.

Kushler, M., Nowak, S., Witte, P., 2014. Examining the Net Savings Issue: A National Survey of State Policies and Practices in the Evaluation of Ratepayer-Funded Energy Efficiency Programs. American Council for an Energy-Efficient Economy.

Kushler, M., Vine, E., York, D., 2002. Energy Efficiency and Electric System Reliability: A Look at Reliability-Focused Energy Efficiency Programs Used to Help Address the Electricity Crisis of 2001. American Council for an Energy-Efficient Economy, Washington, D.C.

Kushler, M., Witte, P., 2003. A Follow-Up Assessment of the Status of Reliability-Focused Energy Efficiency Programs Launched During the Electricity Crisis of 2001: Implications for Policy. American Council for an Energy-Efficient Economy, Washington, D.C.

Kwatra, S., Essig, C., 2014. The Promise and Potential of Comprehensive Commercial Building Retrofit Programs. American Council for an Energy-Efficient Economy.

Laffont, J.-J., 1994. The new economics of regulation ten years after. Econometrica: Journal of the Econometric Society, 507-537.

Lamont, D., Gerhard, J., 2013. The Treatment of Energy Efficiency in Integrated Resource Plans: A Review of Six State Practices. Regulatory Assistance Project.

Larsen, A., Pedersen, L.H., Sørensen, E.M., Olsen, O.J., 2006. Independent regulatory authorities in European electricity markets. Energy Policy 34, 2858-2870.

Lazar, J., Colburn, K., 2013. Recognizing the Full Value of Energy Efficiency (What's Under the Feel-Good Frosting of the World's Most Valuable Layer Cake of Benefits). The Regulatory Assistance Project.

Lee, W.L., Yik, F.W.H., 2004. Regulatory and voluntary approaches for enhancing building energy efficiency. Progress in Energy and Combustion Science 30, 477-499.

Leeuw, F.L., 2003. Reconstructing program theories: Methods available and problems to be solved. American journal of evaluation 24, 5-20.

Leeuw, F.L., 2012. Theory-based evaluation.

Leidos Engineering, 2013. Annual Report: Programme Year 2012 - July 1, 2012 - June 30, 2013. Leidos Engineering LLC. Report Submitted to the Hawaii Public Utilities Commission.

Lerch, D., 2017. STEP up! - German tendering scheme for electrical energy efficiency. Experiences, challenges and further development. Presentation for IEA Workshop on Market-based Instruments (MBIs): Policy choice and design of energy efficiency obligations and auctions, Brussels, Belgium.

Leuthauser, R., Ahlberg, D., Weaver, E., Marr, M., 2005. A Competitive Bidding Program to Encourage Industrial Energy Efficiency, 2005 ACEEE Summer Study on Energy Efficiency in Industry.

Levy, J.S., 2008. Case studies: Types, designs, and logics of inference. Conflict Management and Peace Science 25, 1-18.

Littlechild, S., 2006. Competition and contracts in the Nordic residential electricity markets. Utilities Policy 14, 135-147.

Liu, X., Kong, L., 2016. A New Chapter in China's Electricity Market Reform, Energy Studies Institute Policy Brief. National University of Singapore.

Liu, Y., 2015. Seasonal relationship of peak demand and energy impacts of energy efficiency measures—a review of evidence in the electric energy efficiency programmes. Energy Efficiency, 1-21.

Liu, Y., 2017. Demand response and energy efficiency in the capacity resource procurement: Case studies of forward capacity markets in ISO New England, PJM and Great Britain. Energy Policy 100, 271-282.

Liu, Y., Eyre, N., Darby, S., Keay, M., Robinson, D., Li, X., 2015. Assessment of demand response market potential and benefits in Shanghai. Prepared for Natural Resources Defense Council.

Mallaburn, P.S., Eyre, N., 2014. Lessons from energy efficiency policy and programmesin the UK from 1973 to 2013. Energy Efficiency 7, 23-41.

Mansur, E.T., 2007. Upstream competition and vertical integration in electricity markets. The Journal of Law and Economics 50, 125-156.

March, J.G., 1978. Bounded Rationality, Ambiguity, and the Engineering of Choice. The Bell Journal of Economics 9, 587-608.

Martinot, E., Borg, N., 1998. Energy-efficient lighting programs: Experience and lessons from eight countries. Energy Policy 26, 1071-1081.

Mayne, J., 2001. Addressing attribution through contribution analysis: using performance measures sensibly. The Canadian journal of program evaluation 16, 1.

McAnany, J., 2016. 2016 Demand Response Operations Markets Activity Report: August 2016. PJM Demand Side Response Operations.

Meeus, L., Purchala, K., Belmans, R., 2005. Development of the Internal Electricity Market in Europe. The Electricity Journal 18, 25-35.

MEGEEPA, 2009. 2010-2012 Massachusetts Joint Statewide Three-Year Electric Energy Efficiency Plan. Massachusetts Electric and Gas Energy Efficiency Program Administrators.

MEGEEPA, 2011. Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures: 2012 Program Year - Plan Version. Massachusetts Electric and Gas Energy Efficiency Program Administrators.

MEGEEPA, 2012a. 2013-2015 Massachusetts Joint Statewide Three-Year Electric and Gas Energy Efficiency Plan. Massachusetts Electric and Gas Energy Efficiency Program Administrators.

MEGEEPA, 2012b. Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures: 2013-2015 Program Years - Plan Version. Massachusetts Electric and Gas Energy Efficiency Program Administrators.

MEGEEPA, 2013. Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures: 2012 Program Year - Report Version. Massachusetts Electric and Gas Energy Efficiency Program Administrators.

MEGEEPA, 2015. 2016-2018 Massachusetts Joint Statewide Three-Year Electric and Gas Energy Efficiency Plan. September 25, 2015 Draft. Massachusetts Electric and Gas Energy Efficiency Program Administrators.

Michaels, R.J., 2004. Vertical Integration: The Economics that Electricity Forgot. The Electricity Journal 17, 11-23.

Michals, J., Titus, E., 2006. The Need for the Approaches to Developing Common Protocols to Measure, Track, and Report Energy Efficiency Savings in the Northeast, 2006 ACEEE Summer Study on Energy Efficiency in Buildings.

Mitroff, I.I., Mason, R.O., 1980. Structuring III-structured policy issues: Further explorations in a methodology for messy problems. Strategic Management Journal 1, 331-342.

Molenbroek, E., Smith, M., Surmeli, N., Schimschar, S., Waide, P., Tait, J., McAllister, C., 2015. Savings and benefits of global regulations for energy efficient products: A 'cost of non-world' study. The European Commission. Prepared by Ecofys, Waide Strategic Efficiency, Tait Consulting and Sea Green Tree.

Molina, M., 2014. The Best Value for America's Energy Dollar: A National Review of the Cost of Utility Energy Efficiency Programs. American Council for an Energy-Efficient Economy.

Molina, M., Neubauer, M., Sciortino, M., Nowak, S., Vaidyanathan, S., Kaufman, N., Chittum, A., Sheppard, C., Harper, M., Jacobson, A., Chamberlin, C., Mugica, Y., 2010. The 2010 State Energy Efficiency Scorecard. American Council for an Energy-Efficient Economy.

Monitoring Analytics, 2013. Analysis of Replacement Capacity for RPM Commitments: June 1, 2007 to June 1, 2013.

Monitoring Analytics, 2016. Analysis of the 2018/2019 RPM Base Residual Auction Revised. The Independent Market Monitor for PJM.

Morey, M.J., Kirsch, L.D., 2016. Retail Choice in Electricity: What Have We Learnt in 20 Years? Prepared for Electric Markets Research Foundation. Christensen Associates Energy Consulting.

Morgan, D.L., Guevara, H., 2008. Interview Guide, in: Given, L.M. (Ed.), The SAGE Encyclopedia of Qualitative Research Methods. SAGE Publications, Inc., Thousand Oaks.

Mount, A., Benton, D., 2015. Getting more from less: realising the potential of negawatts in the UK electricity market, Green Alliance Policy Insight. Green Alliance.

Mueller, S., Patnode, A., Bradford, J., Leuthauser, R., Ahlberg, D., 2007. Results of an Industrial Efficiency Bid Program: A Customer-Driven Apporach to Energy Efficiency in Industry, 2007 ACEEE Summer Study on Energy Efficiency in Industry.

Nadel, S., Elliott, N., Langer, T., 2015. Energy Efficiency in the United States: 35 Years and Counting. American Council for an Energy-Efficient Economy.

Nadel, S., Gordon, F., Neme, C., 2000. Using Targeted Energy Efficiency Programs to Reduce Peak Electrical Demand and Address Electric System Reliability Problems. American Council for an Energy-Efficient Economy, Washington, D.C.

Nadel, S., Latham, L., 1998. The Role of Market Transformation Strategies in Achieving a More Sustainable Energy Future. American Council for an Energy-Efficient Economy, Washington, D.C.

NAPEE, 2008. Understanding Cost-Effectiveness of Energy Efficiency Programs: Best Practices, Technical Methods, and Emerging Issues for Policy-Makers. The National Action Plan for Energy Efficiency.

NAPEE, 2010. Customer Incentives for Energy Efficiency Through Program Offerings. Prepared by William Prindle, ICF International, Inc.

National Grid, 2014. Final Auction Results: T-4 Capacity Market Auction 2014.

National Grid, 2015. Final Auction Results: T-4 Capacity Market Auction for 2019/20. National Grid.

Navigant, 2011. Process and Impact Evaluation of Efficiency Vermont's 2007-2009 Geotargeting Program. Prepared for Vermont Department of Public Service. Navigant Consulting Inc., West Hill Energy and Computing Inc., Grimason Associated LLC and Blackstone Group.

Navigant, 2012. Existing Facilities Program: Market Characterization and Assessment Report. Prepared for New York State Energy Research and Development Authority.

Navigant, EMI, 2011. Final Evaluation Report for Wyoming's Energy FinAnswer Program. Prepared for Rocky Mountain Power.

Navigant, EMI, 2012. Final Evaluation Report for Washington's Energy FinAnswer Program (PY 2009 through 2011). Prepared for Pacific Power.

Navigant, EMI, 2013a. Final Evaluation Report for Idaho's Energy FinAnswer Program (PY 2009-11). Prepared for Rocky Mountain Power.

Navigant, EMI, 2013b. Final Evaluation Report for Utah's Energy FinAnswer Program (PY 2009 through 2011). Prepared for Rocky Mountain Power.

Navigant, EMI, 2015a. Evaluation Report for Idaho's Energy FinAnswer Program (PY 2012 through 2013). Prepared for Rocky Mountain Power.

Navigant, EMI, 2015b. Evaluation Report for Washington's Energy FinAnswer Program (PY 2012 through 2013). Prepared for Pacific Power.

Navigant, EMI, 2015c. Evaluation Report for Wyoming's Energy FinAnswer Program (PY 2011 through 2013). Prepared for Rocky Mountain Power.

NEEP, 2015. Regional Energy Efficiency Datab. Northeast Energy Efficiency Partnerships Inc.

NEEP, 2016. The Regional Energy Efficiency Database (REED), in: Partnerships, N.E.E. (Ed.).

Neme, C., Cowart, R., 2013. Energy efficiency feed-in-tariffs: key policy and design considerations, ECEEE 2013 Summer Study European Council for an Energy Efficient Economy.

Neme, C., Cowart, R., 2014. Energy Efficiency Participation in Electricity Capacity Markets - The U.S. Experience. The Regulatory Assistance Project, Montpelier, Vermont.

Neme, C., Sedano, R., 2012. US Experience with Efficiency As a Transmission and Distribution System Resource. Regulatory Assistance Project, Montpelier, Vermont.

NERC, 2013. 2011 Demand Response Availability Report. North American Electric Reliability Corporation.

Newbery, D., 2002. Issues and options for restructuring electricity supply industries, DAE Working Paper WP 0210, Department of Applied Economics, University of Cambridge.

Newbery, D., 2016. Missing money and missing markets: Reliability, capacity auctions and interconnectors. Energy Policy 94, 401-410.

Newbery, D.M., Pollitt, M., 1997. The Restructuring and Privatization of Britain's CEGB--Was It Worth It? Journal of Industrial Economics 45, 269-303.

Newbury, D.M., 1999. Privatization, Restructuring and Regulation of Network Utilities. The MIT Press, Cambridge, MA.

Nexant, 2013. Final Report: Cross-Cutting Evaluation of 2012 Business Incentive Programs. Submitted to Ontario Power Authority. In parternship with Research Into Action, Inc.

Nexant, 2014. Final Report: Evaluation of 2013 Business Incentive Programs. Submitted to Ontario Power Authority.

NMR, 2007. Process and Impact Evaluation of the Low Income Appliance Replacement Program - Final. Nexus Market Research Inc. and RLW Analytics Inc.

NMR, 2014. Northeast Residential Lighting Hours-of-Use Study. NMR Group Inc. and DNV GL. Submitted to Connecticut Energy Efficiency Board, Cape Light Compact, Massachusetts Energy Efficiency Advisory Council, National Grid Massachusetts, National Grid Rhode Island, New York State Energy Research and Development Authority, Northeast Utilities and Unitil.

Nolan, S., O’Malley, M., 2015. Challenges and barriers to demand response deployment and evaluation. Applied Energy 152, 1-10.

Nowak, S., Kushler, M., Sciortino, M., York, D., Witte, P., 2011. Energy Efficiency Resource Standards: State and Utility Strategies for Higher Energy Savings. American Council for an Energy-Efficient Economy, Washington, D.C.

OEB, 2013. Conservation and Demand Management Report - 2012 Results. Ontario Energy Board.

OECD, 1999. Background note on the relationship between regulators and competition authorities. Organisation for Economic Co-operation and Development.

OECD/IPEEC, 2016. G7 Hamburg Initiative for Sustainable Energy Security. Analytical Report on Instruments for Energy Efficiency. OECD and International Partnership for Energy Efficiency Cooperation (IPEEC).

Ofgem, 2013a. Creating the right environment for demand-side response: next steps. Ofgem.

Ofgem, 2013b. The final report of the Carbon Emissions Reduction Target (CERT) 2008-2012. Office of Gas and Electricity Markets, London.

Ofgem, 2015. Insights paper on households with electric and other non-gas heating. Office of Electricity and Gas Markets.

Olsen, O.J., Johnsen, T.A., Lewis, P., 2006. A mixed Nordic experience: implementing competitive retail electricity markets for household customers. The Electricity Journal 19, 37-44.

OPA, 2014. Final Evaluation Report: High Performance New Construction and Residential New Construction Initiatives.

Oren, S., 2005. Ensuring Generation Adequacy in Competitive Electricity Markets, in: Griffin, J.M., Puller, S.L. (Eds.), Electricity Deregulation: Choices and Challenges. Bush School Series in the Economics of Public Policy.

Palmer, J., Terry, N., Kane, T., 2013a. Further Analysis of the Household Electricity Survey - Early Findings: Demand side management. Cambridge Architectural Research Limited, Element Energy and Loughborough University.

Palmer, K.L., Grausz, S., Beasley, B., Brennan, T.J., 2013b. Putting a floor on energy savings: Comparing state energy efficiency resource standards. Utilities Policy 25, 43-57.

Pawson, R., Sridharan, S., 2009. Theory-driven evaluation of public health programmes, in: Killoran, A., Kelly, M.P. (Eds.), Evidence-based Public Health: Effectiveness and efficiency. Oxford Scholarship Online.

Pawson, R., Tilley, N., 2004. Realist Evaluation. Monograph prepared for the British Cabinet Office.

Peterson, P., Hurley, D., Woolf, T., Biewald, B., 2006. Incorporating Energy Efficiency into the ISO New England Forward Capacity Market: Ensuring the Capacity Market Properly Values Energy Efficiency Resources. Synapse Energy Economics, Inc.

Pfeifenberger, J.P., Basheda, G.N., Schumacher, A.C., 2007. What we can learn from retail-rate increases in restructured and non-restructured states, Fornightly Magazine.

Pfeifenberger, J.P., Spees, K., Newell, S.A., 2012. Resource Adequacy in California.

Pfeifenberger, J.P., Spees, K., Schumacher, A.C., 2009. A Comparison of PJM's RPM with Alternative Energy and Capacity Market Designs. The Brattle Group.

PJM, 2010. PJM Manual 18B: Energy Efficiency Measurement & Verification. Revision: 01 Effective Date: March 1, 2010.

PJM, 2011. 2014/2015 RPM Base Residential Auction Results.

PJM, 2012. 2015/2016 RPM Base Residential Auction Results.

PJM, 2013. 2016/2017 RPM Base Residential Auction Results.

PJM, 2014a. 2017/2018 RPM Base Residential Auction Results.

PJM, 2014b. 2017/2018 RPM Base Residential Auction Results.

PJM, 2014c. Problem Statement on PJM Capacity Performance Definition.

PJM, 2015a. Capacity Performance at a Glance.

PJM, 2015b. PJM Manual 11: Energy & Ancillary Services Market Operations. Revision: 76. Effective Date: August 03, 2015.

PJM, 2015c. PJM Manual 18: PJM Capacity Market. Revision: 28. Effective Data: August 3, 2015.

Platts, 2013. EnerNOC Thinning Position in New England Forward Capacity Market, Platts, Washington, D.C.

Plunkett, J., Weston, F., Crossley, D., 2012. Government Oversight of Grid Company Demand-Side Management Activities in China: Recommendations from International Experience. Regulatory Assistance Project.

Pollitt, M., 1999. Issues in Electricity Market Integration and Liberalization. Centre for Economics Policy Research, London.

Pollitt, M., 2008. Foreword: Liberalization and Regulation in Electricity Systems – How can We get the Balance Right?, in: Sioshansi, F.P. (Ed.), Competitive Electricity Markets. Elsevier, Oxford, p. xxxiv.

Poudineh, R., Jamasb, T., 2014. Distributed generation, storage, demand response and energy efficiency as alternatives to grid capacity enhancement. Energy Policy 67, 222-231.

Price, A., 2013. Enernoc Exits ISO New England Demand Response Program. Competitive Energy Services.

Prior, L.F., 2008. Document Analysis, in: Given, L.M. (Ed.), The SAGE Encyclopedia of Qualitative Research Methods. SAGE Publications, Inc., Thousand Oaks.

Pudjianto, D., Djapic, P., Aunedi, M., Gan, C.K., Strbac, G., Huang, S., Infield, D., 2013. Smart control for minimizing distribution network reinforcement cost due to electrification. Energy Policy 52, 76-84.

Quantum Consulting, 2004. National Energy Efficiency Best Practices Study. Volume NR5 - Non-Residential Large Comprehensive Incentive Programs Best Practices Report. Submitted to Pacific Gas and Electric Company by Quantum Consulting.

Radgen, P.D.P., Bisang, D.K., Koenig, I., 2016. Competitive Tenders for Energy Efficiency - Lessons Learnt in Switzerland, ECEEE Industrial Summer Study proceedings –Industrial Efficiency 2016. European Council for an Energy Efficient Economy (ECEEE).

Rearch Into Action, 2011. Final Report: Cross-Cutting Commercial and Institutional (C&I) Retrofit Incentive Initiatives 2009-2010 Evaluation Report. Funded by Ontario Power Authority. Prepared by Research Into Action, Inc.

Reeves, A., 2011. Making it viable: exploring the influence of organisational context on efforts to achieve deep carbon emission cuts in existing UK social housing. Energy Efficiency 4, 75-92.

Riché, M., 2012. Theory Based Evaluation: A wealth of approaches and an untapped potential. European Commission.

Robson, C., McCartan, K., 2016. Real world research. John Wiley & Sons.

Rohde, C., Rosenow, J., Eyre, N., Giraudet, L.-G., 2015. Energy saving obligations—cutting the Gordian Knot of leverage? Energy Efficiency 8, 129-140.

Roques, F.A., 2008. Market design for generation adequacy: Healing causes rather than symptoms. Utilities Policy 16, 171-183.

Rosenberg, M., Hoefgen, L., 2009. Market Effects and Market Transformation: Their Role in Energy Efficiency Program Design and Evaluation. California Institute for Energy and Environment.

Rosenow, J., 2012. Energy savings obligations in the UK—A history of change. Energy Policy 49, 373-382.

Rosenow, J., Eyre, N., 2013. The green deal and the energy company obligation. Proceedings of the ICE-Energy 166, 127-136.

Rosenow, J., Eyre, N., 2015. Re-energising the UK's approach to domestic energy efficiency, ECEEE Summer Study Proceedings.

Rosenow, J., Eyre, N., 2016. A post mortem of the Green Deal: Austerity, energy efficiency, and failure in British energy policy. Energy Research & Social Science 21, 141-144.

Rosenow, J., Fawcett, T., Eyre, N., Oikonomou, V., 2016a. Energy efficiency and the policy mix. Building Research & Information 44, 562-574.

Rosenow, J., Galvin, R., 2013. Evaluating the evaluations: Evidence from energy efficiency programmes in Germany and the UK. Energy and Buildings 62, 450-458.

Rosenow, J., Leguijt, C., Pató, Z., Eyre, N., Fawcett, T., 2016b. An ex-ante evaluation of the EU Energy Efficiency Directive - Article 7. Economics of Energy & Environmental Policy 5.

Rosenzweig, M.B., Fraser, H., Falk, J., Voll, S.P., 2003. Market Power and Demand Responsiveness: Letting Customers Protect Themselves. The Electricity Journal 16, 11-23.

Rowlinson, M., Procter, S., 1997. Efficiency and Power: Organizational Economics Meets Organization Theory. British Journal of Management 8, 31-42.

RTO Insider, 2013. Has Demand Response Peaked? RTO Insider.

Salies, E., Price, C.W., 2004. Charges, costs and market power: the deregulated UK electricity retail market. The Energy Journal, 19-35.

Sanstad, A.H., Howarth, R.B., 1994. ‘Normal’ markets, market imperfections and energy efficiency. Energy Policy 22, 811-818.

Schiellerup, P., 2002. An examination of the effectiveness of the EU minimum standard on cold appliances: the British case. Energy Policy 30, 327-332.

Schubert, E.S., Hurlbut, D., Adib, P., Oren, S., 2006. The Texas Energy-Only Resource Adequacy Mechanism. The Electricity Journal 19, 39-49.

Schweitzer, M., Hirst, E., Hill, L., 1991. Demand-Side Management and Integrated Resource Planning: Findings from a Survey of 24 Electric Utilities. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Sciortino, M., Neubauer, M., Vaidyanathan, S., Chittum, A., Hayes, S., Nowak, S., Molina, M., Sheppard, C., Jacobson, A., Chamberlin, C., Mugica, Y., 2011. The 2011 State Energy Efficiency Scorecard. American Council for an Energy-Efficient Economy.

Scottish Government, 2015. Scottish House Condition Survey: 2014 Key Findings. The Scottish Government.

Scottish Government, 2016a. Housing Statistics for Scotland - Key Information and Summary Tables - Updated after Scottish Household Survey 2015 was published, in: Government, S. (Ed.).

Scottish Government, 2016b. Scottish House Condition Survey: 2015 Key Findings. The Scottish Government.

Scottish Housing Regulator, 2017. Directory of Social Landlords.

SEDC, 2015. Mapping Demand Response in Europe Today 2015. Smart Energy Demand Coalition.

SEEAction, 2012. Energy Efficiency Program Impact Evaluation Guide: Evaluation, Measurement, and Verification Working Group. Department of Energy.

Shen, B., Ghatikar, G., Lei, Z., Li, J., Wikler, G., Martin, P., 2014. The role of regulatory reforms, market changes, and technology development to make demand response a viable resource in meeting energy challenges. Applied Energy 130, 814-823.

Simon, H.A., 1966. Theories of Decision-Making in Economics and Behavioural Science, Surveys of Economic Theory: Resource Allocation. Palgrave Macmillan UK, London, pp. 1-28.

Sinton, J., Wit, J.d., 2014. Exploring Market-Based Mechanisms to Meet Utilities' Energy Efficiency Obligations. World Bank.

Sioshansi, F.P., 2006a. Electricity market reform: What has the experience taught us thus far? Utilities Policy 14, 63-75.

Sioshansi, F.P., 2006b. Electricity Market Reform: What Have We Learned? What Have We Gained? The Electricity Journal 19, 70-83.

Sioshansi, F.P., 2008a. Competitive Electricity Markets: Design, Implementation, Performnce. Elsevier.

Sioshansi, F.P., 2008b. Competitive Electricity Markets: Questions Remain about Design, Implementation, Performance. The Electricity Journal 21, 74-87.

Sioshansi, F.P., 2013. Evolution of Global Electricity Markets: New paradigms, new challenges, new approaches. Academic Press.

Sioshansi, F.P., Pfaffenberger, W., 2006a. Chapter 1 - Why Restructure Electricity Markets?, in: Sioshansi, F.P., Pfaffenberger, W. (Eds.), Electricity Market Reform. Elsevier, Oxford, pp. 35-48.

Sioshansi, F.P., Pfaffenberger, W., 2006b. Electricity Market Reform: An International Perspective. Elsevier.

SmartGrid GB, 2013. Energy Bill 2013: Demand Side Response and the Capacity Market in focus. SmartGrid GB.

Smith, D., 2013. Real Time Demand Resource Performance - July 19th 2013 OPA4 Action 2 Dispatch.

Smith, D., 2014. Demand Resource Performance Winter 2013-14 - Audits of all Demand Resource Types, and RTDR and Winter Reliability Program Dispatches.

Sorrell, S., 2015. Reducing energy demand: A review of issues, challenges and approaches. Renewable and Sustainable Energy Reviews 47, 74-82.

Sorrell, S., Schleich, D.J., Scott, D.S., O'Malley, E., Trace, F., Boede, U., Ostertag, K., Radgen, D.P., 2000. Understanding barriers to energy efficiency. Barriers to Energy Efficiency in Public and Private Organsiations. Final Report to the European Commission. SPRU Environment and Energy, University of Sussex.

Sousa, J.L., 2017. Portuguese Plan for Promoting Efficiency of Electricity End-Use. Presentation for IEA Workshop on Market-based Instruments (MBIs): Policy choice and design of energy efficiency obligations and auctions, Brussels, Belgium.

Sousa, J.L., Jorge, H.M., Martins, A.G., 2015. Are energy efficiency obligations an alternative? The case-study of Portugal, ECEEE Summer Study Proceedings 2015. European Council for an Energy Efficient Economy.

SPEER, 2013. Toward a More Efficient Electric Market: New Frameworks for Advancing Energy Efficiency in Texas - Considerations and Suggestions for Inclusion of Energy Efficiency as a Resource in the ERCOT Market. The South-central Partnership for Energy Efficiency as a Resource.

Spees, K., Newell, S.A., Pfeifenberger, J.P., 2013. Capacity markets-lessons learned from the first decade. Economics of Energy & Environmental Policy 2.

Steg, L., 2008. Promoting household energy conservation. Energy Policy 36, 4449-4453.

Steiner, F., 2001. Regulation, Industry Structure and Performance in the Electricity Supply Industry. OECD Economic Studies, No. 32.

Stern, J., 1997. What Makes an Independent Regulator Independent? Business Strategy Review 8, 67-74.

Stern, P.C., 1986. Blind spots in policy analysis: What economics doesn't say about energy use. Journal of Policy Analysis and management 5, 200-227.

Strbac, G., 2008. Demand side management: Benefits and challenges. Energy Policy 36, 4419-4426.

Stridbaek, U., 2005. Lessons from liberalised electricity markets. OECD, Paris.

Suchman, E., 1968. Evaluative Research: Principles and Practice in Public Service and Social Action Progr. Russell Sage Foundation.

Sutherland, R.J., 1996. The economics of energy conservation policy. Energy Policy 24, 361-370.

Swisher, J.N., 1996. Regulatory and Mixed Policy Options for Reducing Energy Use and Carbon Emissions. Mitigation and Adaptation Strategies for Global Change 1, 23-49.

Thatcher, M., Sweet, A.S., 2002. Theory and Practice of Delegation to Non-Majoritarian Institutions. West European Politics 25, 1-22.

The Brattle Group, 2007. Quantifying Demand Response Benefits in PJM. PJM Internconnection, LLC and the Mid-Atlantic Distributed Resources Initiative (MADRI), Cambridge, MA.

Torriti, J., Hassan, M.G., Leach, M., 2010. Demand response experience in Europe: Policies, programmes and implementation. Energy 35, 1575-1583.

UKPN, 2014a. Conflicts and synergies of Demand Side Response. Uk Power Networks.

UKPN, 2014b. Industrial and Commercial Demand Response for outage management and as an alternative to network reinforcement. UK Power Networks.

UKPN, 2014c. Network impacts of energy efficiency at scale. UK Power Networks.

Vidalenc, E., Meunier, L., 2011. Smart grid versus energy efficiency: Which one first?, ECEEE 2011 Summer Study - Energy Efficiency First: the Foundation of a Low-Carbon Society.

Vine, E., 2008. Breaking down the silos: the integration of energy efficiency, renewable energy, demand response and climate change. Energy Efficiency 1, 49-63.

Wade, J., Eyre, N., 2015a. Energy Efficiency Evaluation: the evidence for energy savings from energy efficiency programmes in the household sector. UK Energy Research Centre.

Wade, J., Eyre, N., 2015b. Energy Efficiency Evaluation: The evidence for real energy savings from energy efficiency programmes in the household sector. UK Energy Research Centre.

Walawalkar, R., Fernands, S., Thakur, N., Chevva, K.R., 2010. Evolution and current status of demand response (DR) in electricity markets: Insights from PJM and NYISO. Energy 35, 1553-1560.

Ward, J., Pooley, M., Owen, G., 2012. Paper 4: What Demand-Side Services Can Provide Value to the Electricity Sector?, GB Electricity Demand - Realising the resource. Sustainability First.

Watts, K., Metternich, F., 2014. Kickstarting the negawatts market: how to make sure the electricity demand reduction pilot succeeds. Green Alliance.

Weiss, C.H., 1995. Nothing as practical as good theory: Exploring theory-based evaluation for comprehensive community initiatives for children and families. New approaches to evaluating community initiatives: Concepts, methods, and contexts 1, 65-92.

Weiss, C.H., 1997. Theory-based evaluation: Past, present, and future. New Directions for Evaluation 1997, 41-55.

Welsh Government, 2016. Dwelling stock estimates for Wales, 2014-15, in: Statistics for Wales, W.G. (Ed.).

WHEC, 2010. Verification of Efficiency Vermont's Energy Efficiency Portfolio for the ISO-NE Forward Capacity Market: Final Report. West Hill Energy and Computing Inc.

WHEC, 2012a. Verification of Efficiency Vermont's Energy Efficiency Portfolio for the ISO-NE Forward Capacity Market: Final Report. West Hill Energy and Computing Inc.

WHEC, 2012b. Verification of EVT 2011 Claimed Annual MWh Savings, Coincident Summer and Winter Peak Savings and Total Resource Benefit (TRB). West Hill Energy and Computing Inc.

WHEC, 2013. Verification of EVT 2012 Claimed Annual MWh Savings, Coincident Summer and Winter Peak Savings and Total Resource Benefit (TRB): Final Report. West Hill Energy and Computing Inc.

White, H., 2009. Theory-Based Impact Evaluation: Principles and Practice. International Initiative for Impact Evaluation, Working Paper 3.

White, M., 1996. Power Struggles: Explaining Deregulatory Reforms in Electricity Markets, Brookings Papers on Economic Activity: Microeconomics. The Brookings Institute, pp. 201-250.

Wholey, J.S., 1987. Evaluability assessment: Developing program theory. New Directions for Evaluation 1987, 77-92.

Woo, C.-K., Lloyd, D., Tishler, A., 2003. Electricity market reform failures: UK, Norway, Alberta and California. Energy Policy 31, 1103-1115.

Yin, R., 2003. Case study research: Design and methods (3rd ed.). SAGE, Thousand Oaks, CA.

Yin, R.K., 1981. The case study as a serious research strategy. Knowledge 3, 97-114.

York, D., Kushler, M., Witte, P., 2007. Examining the Peak Demand Impacts of Energy Efficiency: A Review of Program Experience and Industry Practices. American Council for an Energy-Efficient Economy, Washington, D.C.

York, D., Molina, M., Neubauer, M., Nowak, S., Nadel, S., Chittum, A., Elliott, N., Farley, K., Foster, B., Sachs, H., Witte, P., 2013. Frontiers of Energy Efficiency: Next Generation Programs Reach for High Energy Savings. American Council for an Energy-Efficient Economy.

Zarnikau, J.A.Y., 2008. Chapter 8 - Demand Participation in Restructured Markets A2 - Sioshansi, Fereidoon P, Competitive Electricity Markets. Elsevier, Oxford, pp. 297-324.

Zarnikau, J.W., 2010. Demand participation in the restructured Electric Reliability Council of Texas market. Energy 35, 1536-1543.