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RetroMeter Literature Review:

A qualitative estimate of consumer propensity to engage with RetroMeter and an exploration of the values of residential energy efficiency at the scale of the GB system.

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Glossary of Terms:

EE:	Energy Efficiency - the process of reducing the amount of energy required to provide products or services.
Grid Balancing:	Ensuring that energy supply meets demand on a second-by-second basis. For the UK electricity system this is done by the Electricity System Operator
Load Forecasting:	The prediction of future demand for energy.
Demand flexibility:	Capability of demand-side loads to change their consumption patterns.
SMETER:	UK Smart Meter Enabled Thermal Efficiency Ratings Innovation Programme, which evaluated approaches to calculate the Heat Transfer Coefficient (HTC) of occupied homes from smart meter data.
ICO:	Information Commissioner's Office - a non-departmental public body that upholds information rights in the public interest.
DNOs:	Distribution Network Operators - licensed companies that own and operate the electricity network from the National Gid intake (132kV) to the end users.
ADMD:	After Diversity Maximum Demand – An index used in the design of electricity network infrastructure to meet anticipated demand on the network, where demand is aggregated over many customers and accounts for peak load a network is likely to experience over its lifetime (an overestimation of typical demand).
RIIO-ED1 Framework:	Ofgem's framework for setting price controls for operators of the 14 electricity distribution networks between April 2015 and March 2023.
ESO:	Electricity System Operator for Great Britain, that moves electricity from where it is generated through the energy system.

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Part 1: Qualitative estimate of consumer propensity to engage with projects like RetroMeter.

1. **Problem Background:**
    a. Consumers do not understand who their data is being sold to or how it is used.
    b. Low trust in organisations means consumers may not be willing to engage in projects like Retrometer.
    c. Consumers are concerned about privacy and security threats if their data is shared without their consent.
2. **Problem Statement:**
    a. Are consumers happy to share smart meter energy data? Do they understand how their data is being used?
    b. How do we increase consumers' propensity to participate in these studies? What methods can be used to alleviate consumer's concerns around privacy and security?
3. **Objectives of Literature Review:**
    a. Summarise studies on general consumer attitudes, globally and locally (if data available) towards smart meter energy data collection.
    b. Identify why consumers may hesitate to share data / have low trust in energy service companies.
    c. Propose how consumer attitudes have been shifted positively in past studies.

Introduction to data sharing concerns:

In order to achieve net zero carbon emissions in the UK by 2050, decarbonisation of 27 million homes is required through a combination of energy efficiency (EE) measures and low carbon heating. For this to happen, consumers, energy operators and financial providers alike must be able to quantify the energy saving benefits of refurbishments and low carbon technologies.

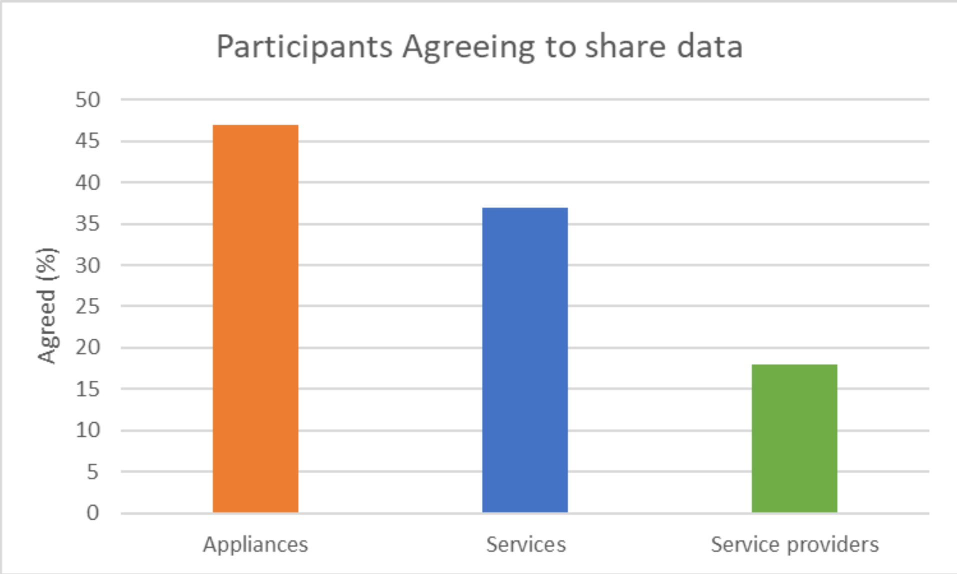
Ongoing conversion of current gas and electricity networks to smart grids is going to play a pivotal role in quantifying these savings, of which the prerequisite will be to roll out smart meters nationally. These meters transmit information about consumer electricity usage to utility companies at short intervals. They offer a variety of benefits, such as increased convenience and control over personal energy use to the consumer. At the national level, smart meters enable grid-balancing, load forecasting, an estimation of demand side flexibility and a plan for the operation of distributed assets within future energy systems, such as renewable resources.

However, this information can also be used by companies to estimate the movement patterns, occupancy states and in certain cases, income of individual households, which poses serious privacy issues and security threats if data is not handled cautiously. Moreover, as energy is often an abstract commodity, the general public's awareness and knowledge about smart meters and their benefits is limited. Moreover, data aggregation and prevalent practices of data-trading and machine learning lead to utility companies' lack of transparency about the way in which data is used. As such, data sharing concerns are increasingly being raised by consumers, which, when not addressed diligently, result in lowering the consumer propensity to engage in projects that involve data collection through 'smart' technologies, such as RetroMeter. Consequently, it is imperative to understand the current consumer attitudes towards data sharing, and thus, evaluate the tried and tested methods to mitigate those concerns.

How do consumers feel about sharing personal data?

Consumers understand that personal data is valuable to platforms and agree that companies benefit most from data processing for their own benefit. However, most consumers are not sure what data is held online and only have a basic understanding of data processing that comes from easily visible uses of data. Overall, consumers are largely unaware of how organisations are using personal data, which makes them more wary of the privacy threats associated with sharing their data; Generally, this tends to reduce their willingness to share personal data on offered services and their providers.

However, findings from a survey done on over 701 participants in the UK showed that participants' willingness to share data was highly contextual and dependant on the type of data being disclosed. Participants' willing to share data was also affected by their perception of how the data was shared, what benefits they received from sharing their data and who it was being shared to; 47% of participants agreed to share location data from their heating appliances, 37% agreed to share data for energy savings, but only 18% agreed to share data with an energy utility company (Phil Grünewald, 2020).



According to this study, consumers were more willing to share data for services rather than to service providers. This demonstrates how participants are unable to bridge the knowledge gaps between the stages of data sharing through their appliances, for the services they use to how their data is being used and by who; In general, consumers seem to struggle between differentiating data uses from the organisations that gain access to it, with only 15% of participants claiming to understand who has access to their data. This is because only a small minority of consumers actually read privacy policies, and of those that do, the Information Commissioner's Office (ICO) found that only 16% said they had a good understanding of what was written.

Another reason for consumers reluctance to share data to service provides is because consumers find it difficult to engage with companies collecting and using their data, resulting in them having low trust in these companies. Low engagement is often due to consumers feeling:

a. Disempowered by the lack of knowledge and transparency around how companies use and share data;
b. It is hard to access and change personal information;
c. Reliant on data-driven services they believe they cannot give up;
d. There is lack of alternatives if they want to stop using specific companies.

Other studies have also shown that while consumers do not mind utility companies simply collecting their personal information, their concerns lie in the utility company's ability to analyse information to gain an understanding of their household patterns. These concerns are further amplified when devices installed to collect data are also able to be remotely controlled by said service providers to change consumption patterns (Christine Horne, 2015). Thus, consumer propensity to engage in projects that involve data sharing is significantly reduced when data sharing is perceived to be happening without the consumers' consent, especially in cases where consumers feel like utility companies are sharing data with private companies, such as advertisers.

Interestingly, other studies have reported higher percentages of consumers open to, and accepting of, data sharing through appliances, such as smart meters, particularly when there is a clear benefit to the consumer. A Turkish survey done on 504 participants showed that around 71% of participants desired to get more information about their use of electricity, 72% said that having real time information of energy consumption would be useful for them and 76% said they would prefer having fluctuating unit rates for electricity during the day, so that they can consume more when electricity is cheaper. (Chawla Y, 2020). This aligns with the findings from the UK Smart Meter Enabled Thermal Efficiency Ratings Innovation Programme (SMETER); In the study, smart meters were installed in 30 homes across North West England and the findings suggested that 93% of households said they would be happy to have a SMETER product in their home forever, with 97% reporting that they did not notice the SMETER product in their home at all (Loughborough University, 2022).

Whilst many of the participants in these studies recognised the benefits of data sharing and did not mind having smart appliances in their house, over half were afraid of a privacy breach if companies had access to the data for their detailed electricity usage. This is coupled with findings that suggest increased threats to privacy created by smart meters are likely to provoke strong demand for norms opposing the technology. Consequently, consumers want to have better control over how their data is used or shared once they have signed up to a platform. If a smart energy system, based on significant data sharing, is to be achieved consensually, trust in organisations collecting and sharing the data needs to be addressed.

Methods to alleviate concerns:

Trust is a key consumer issue, often due to lack of transparency, personal control and security. As such, consumers have been shown to be more comfortable with data sharing and processing when companies:

1. Demonstrate a clear benefit to using the data for the consumer:

Small incentives are shown to influence consumers to disclose more data than they otherwise would, which is evident in the high willingness of consumers to share a significant amount of personal data in real life. A study done by KPMG showed that while 79% of the respondents were concerned about providing their personal mobile usage data to external organisations, 58% still agreed to grant them access if it reduced their mobile internet charges. Another study by Ofcom demonstrated how 68% of consumers are happy to provide personal information online to companies in order to obtain something they want. Another example is Carbon Co-op's PowerShaper Flex project trail, in which incentives to participate were offered to people, such as compensation vouchers to emulate being paid to provide flexibility to the grid, and free kit like EV chargers and solar diverters. Feedback from this trail showed high willingness of people to share information relating to their personal energy use.

This idea of consumer preferences becoming more lenient the greater the perceived gains from data provision should be leveraged in the pilot stages of the RetroMeter project; Consumers should be shown a clear advantage of metering their energy usage and sharing this data, by highlighting the importance of accurately quantifying energy savings from energy efficiency retrofits. For example, a more energy efficient home will result in the reduction of householder's energy bills, along with an improvement in the resident's comfort. This could be extended to commercial assets, such as workplaces, in which employees could be shown the relevance of energy consumption monitoring to successful completion of work tasks through health benefits and improved productivity. For more information on the benefits of metering energy consumption, please refer to pages 26 to 37 in the WP3 D5-D8 Delivery Model Options report.

2. Address the approaches taken to mitigate privacy threats associated with data collection and analysis:

Participants' response to the first survey indicates that initial privacy by default design settings could be beneficial, combined with choices that nudge the consumer to make decisions better aligned with their privacy objectives (Phil Grünewald, 2020). As such, the RetroMeter project team using participants' smart meter data should reduce privacy threats by:

- Introducing anonymization capabilities;
- Collecting personal information essential and relevant to a specific service;
- Collecting information that is not sensitive;
- Aggregating data across large datasets;
- Keeping the amount of data they store to a minimum;
- Storing the data securely;
- Deleting the data after use;

This enhanced control and awareness has shown to positively affect individuals' willingness to share data and all relevant measures should be taken by companies wanting to access and process personal consumer data, in line with GDPR.

3. Create concise, simplified data sharing policies:

A large portion of the population does not understand who has access to their data, predominantly because they are unable to thoroughly read and understand all the privacy policies or terms and conditions associated with the 'smart appliances' in their house.

Information asymmetries along with cognitive limitations play a key role in this lack of understanding. Consequently, the RetroMeter project team aim to:

- Increase transparency about the information collected and how it will be used, as well as if it will be passed onto a third party;
- Proactively provide clear and consistent information about consumer implications of consenting to supply personal data;
- Give participants the ability to opt out of sharing their data when they want and to choose who their data will be shared with through an 'approved list' of organisations.

This should be done through a short, simplified and clearly written data sharing policy document or terms and condition document, which should be given to participants, and should highlight the key aspects of data sharing through quality cues, whilst avoiding jargon.

4. Governmental bodies process their data instead of commercial third parties.

RetroMeter's project team should highlight the involvement of a local authority in the Pilot Phase program, to build the participants' confidence around data processing being done in line with GDPR. It should be highlighted that RetroMeter's data requirements are essential to develop a tool that benefits the participants' themselves and aligns with UK's net zero targets, rather than for a commercial monetary gain.

Research left to do:

Most empirical studies look at data sharing preferences as simplistic, self-contained exchanges, in which a type of service is provided in return for a type of data. Risks relating to unsolicited access and secondary uses remain largely unaddressed and may need to be researched in more depth in the next phase of the project.

Part 2: Value of residential energy efficiency (total and cost-effective) at the scale of the UK electric system

1. **Problem Background:**
   a. Goals to decarbonise the power system are leading to the substitution of dispatchable, fossil-fuelled power plants to decentralized and fluctuating solar- and wind- driven power generation.
   b. Electricity demand is predicted to go up over time, and more problematically, go up very suddenly when heating and transport (heat pumps and EVs) are tackled around the same time.
2. **Problem Statement:**
   a. Are there multiple sources of value to the grid for EE projects?
   b. How can these values be ‘stacked’ to present a compelling argument to grid operators?
3. **Objectives of Literature Review:**
   a. Demonstrate how measuring accurate energy savings from a retrofitted project can be regarded as a grid resource.
   b. Determine the values of residential energy efficiency in terms of total value and cost-effective value at the scale of the GB system.

Introduction to the importance of energy efficiency:

Ongoing decarbonisation of the UK power system has meant substituting dispatchable, fossil-fuelled power plants to decentralized solar- and wind- driven power generation. However, this results in increased variability of supply, which means power system operators require more options to efficiently handle the stability and adequacy challenges of the power grid. Studies in California and Australia have shown that with large amounts of solar power, grids are struggling to address the mismatch between daytime solar supply and evening demand (duck curve). Regions with high penetration of wind, like Texas, face similar challenges, albeit with different curves.

Alongside this, electricity demand is predicted to go up over time, and more problematically, predicted to go up suddenly when the electrification of heating and transport (heat pumps and electric vehicles) happens simultaneously. In 2022, The UK Department for Transport reported that there were 327,000 registered electric vehicles (EV), which was a 77% rise compared to the number of EVs in 2020. By 2030, the UK expects to have 300,000 public EV charge points, with around 6000 new charge points being installed each month, which evidences the rapid growth in these low carbon technologies. This, in combination with the radical change from the classic 'dual fuel' scenario, in which houses are expected to replace their gas boilers to heat pumps, means that regulators, utilities and energy companies will undergo an unprecedented transformation of the energy system. National Grid Electricity Distribution (formerly Western Power Distribution) predicts that this transformation will double Great Britain domestic electricity consumption between 2021 to 2050, to an annual total of 195 TWh (Lock, 2021).

Approved network company investment plans have traditionally focussed on investing in poles, wires and substations to tackle this rise in electricity demand. Electricity reliability has also been secured through a mix of generators on the system, including flexible resources to supply balancing as needed. This conservative approach has been successful so far in meeting consumer electricity demands, but also means Distribution Network Operators (DNOs) will have to invest significant amounts of funds moving forward to meet rapidly accelerated demands. Furthermore, in non-smart electric systems, predictions about energy consumption are often based on peak consumption, which results in needing to invest a proportionally higher amount to meet growing demand predictions. Residential energy efficiency could be a method to reduce peak consumption, and thus reduce the amount of investment needed in network reinforcement.

Thus, this literature review examines some of the value streams that residential energy efficiency could bring to the UK electricity grid through a project like RetroMeter.

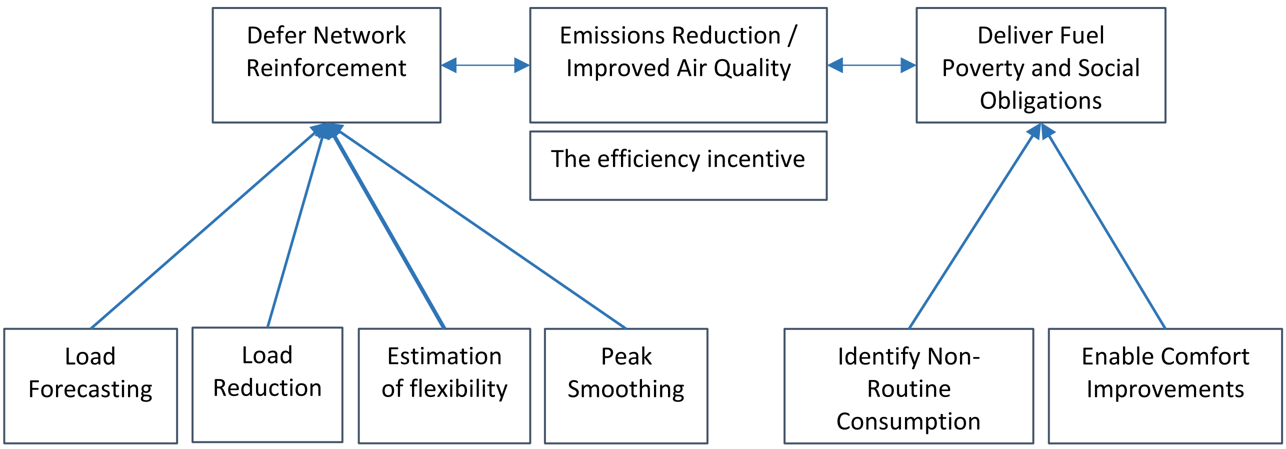
Total value of EE to the UK electric grid:

Energy efficiency (EE) interventions in buildings may affect power consumption in two ways:

1. Permanently decrease power consumption by improving efficiency of a piece of electric equipment or reducing total amount of work performed by existing piece of electric equipment.
2. Permanently increase power consumption due to fuel substitution, such as when a gas fuelled boiler is replaced by an electric heat pump.

EE interventions could also include the installation of smart technology that harness demand profiles, and thus, enable grid operators to shift demand dynamically.

Amalgamating the outcomes of these scenarios opens a plethora of value streams for the UK electricity grid, summarised in the diagram below:



1. Defer Network Reinforcement:

- **Permanent Load Reduction:** In the first scenario, EE measures can lead to permanent demand reduction through improvements in the efficiency of electrical equipment. Thus, retrofits focused on implementing EE measures can be used to reduce peak demand during hours when probability of load loss is high or hours when persistent variability in the net load (difference between total system load and electricity generation from renewable sources) leads to ramping events. As electricity demand rapidly grows, these outcomes could result in fewer networks requiring reinforcement.
- **Dynamic Load Shift:**
    - **Load Forecasting / Peak Smoothing / Estimation of Demand Side Flexibility:** In the third scenario, residential EE can be used as a vehicle to accelerate the implementation of smart metering, which will result in frequent collection of data on householders' electricity usage. Following the development of an intra-day version of the Measurement & Verification protocol, the industry can harness daily customer demand profiles, which could include electric vehicle charging times and heat pump usage times, to forecast the daily load and help smooth the new peaks and troughs of an increasingly dynamic electricity system, whilst enabling grid-balancing. Load shape can be valued as well as overall reduction or growth, which will make it possible for EE projects to participate in flexibility markets at the distribution (DNO) or national (ESO) level. In particular, grid operators can use these demand profiles to increase participation in demand side flexibility, which can lead to the lowering of energy costs by limiting consumption at peak times when energy is more expensive. Smart Metering enables demand response participants to be notified of the grid instability in advance, thus enabling them to prepare proactively against potential outages and therefore protect the continuity of their operations. Moreover, monitoring consumer electricity consumption contributes towards creating a smart grid in which predictions on growing demand are more accurate and do not need to be based solely on peak demand. This allows grid operators to plan for the operation of distributed assets, such as renewable resources, within future energy systems more accurately.

As a result, flexibility and EE can become complementary, and implementing both simultaneously will be of a higher value to grid operators than separately, to avoid future investments in generation capacity and network reinforcement.

2. Deliver fuel poverty and social obligations:

The RIIO-ED1 framework incentivises DNOS to investigate in new and alternative operational solutions, outside of their traditional duty of delivering electricity to customers. One area within this framework describes DNO's social obligations, such that DNOs should assume greater responsibility towards helping fuel poor and vulnerable households.

- **Identify non-routine consumption:** EE measures that implement smart metering to harness customer demand profiles can also be used to identify non-routine energy consumption, such as underheating of homes, in communities where fuel poverty is prevalent. Through this identification, grid operators can improve their network forecasting and deploy assets where most needed.
- **Enable Comfort Improvements:** The implementation of EE retrofits in these households oftentimes results in comfort takeback, in which householders use more electricity than they did prior to the retrofit to live in a more comfortable environment. This could range from heating the house up to a more comfortable temperature, using lights more frequently and taking warmer showers. This improved social prescribing will lead to a reduction in the public sector healthcare costs due to fewer hospital admissions due to poor indoor quality of life. Moreover, these comfort improvements will enable DNOs to deliver their social obligations.

The efficiency incentive: This is a price control framework that regulates all DNOs activities. As part of this framework, efficiencies gained by DNOs through more cost-efficient methods than those agreed at beginning of price control are shared between businesses and its customers. DNOs keep a share of the savings that result from their effort to invest at lesser costs than originally planned. In this case, EE measures will enable DNOs to avoid cost-inefficient future scenarios. For example, EE retrofits done prior to households undergoing the electrification of heat will result in reduction of electricity usage and thus lowering the need for an over-large and inefficient heat pump. This is more cost efficient compared to consumers installing large heat pumps without demand reduction, and then using a DNO flexibility payment to fund EE measures. While both scenarios will see a rise in electricity use, the latter means DNOs will see a reduction on an avoided future scenario, and thus, can leverage the efficiency incentive framework.

Improved Air Quality: In both the peak demand reduction and load shaping scenarios, EE measures are able to relieve pressure on power storage deployments to support renewable energy integration, thus helping to phase out old, polluting power plants commissioned for provision of capacity reserves, whilst reducing the amount of new generation capacity needed to serve the future load growth. As a result, EE measures contribute to the reduction of harmful emissions from the electric grid, and thus, improve outdoor air quality. From a grid operator perspective, this becomes valuable in the form of carbon trading and brings the grid operator closer to achieving their net zero carbon goals. From a government perspective, improved air quality leads to a reduction in public sector healthcare costs due to fewer hospital admissions linked with air quality-related diseases.

For more detailed depictions and descriptions of the value streams of energy efficient retrofits, at the household, DNO and grid level, please refer to pages 31 to 37 in the WP3 D5-D8 Delivery Model Options report.

Cost-effect value:

The value of an EE project is highly dependent on the temporal profile of power consumption changes that it induces: A grid positive energy retrofit project is where the positive outweighs the negative impacts to the grid. Reductions of load during peak periods can be highly valuable as a grid resource and mitigate substantially more CO_2 emissions by displacing electrons from some of the fossil fuel powered plants. This value is increased when the coordination between the needs of the power system and incentives for energy efficiency improvements take place during the medium-term planning for resource adequacy in the power system.

Retrofits predominantly focus on heat. How energy vector for heat fits in with benefits for DNOS, and retrofit focused on reducing heating energy demand will depend on 3 scenarios:

1. Heating in households is already electrified, which means the reductions in heating demand immediately benefit the DNO.
2. The gas heating demand in households is reduced, which means that reductions in heating demand do not immediately benefit the DNO, but will in future if, or when, heating is electrified.
3. Heat is electrified (in combination with EE measures) during the retrofit, which means that heating demand reduces but the electricity demand increases due to fuel change. Whether a DNO benefits in this scenario depends on whether the counterfactual baseline is defined as the previous gas-heated state or as an ‘electrified without EE measures’ state. One could argue that the conversion of heat from gas to electric is bound to happen, regardless of EE measures, and thus the counterfactual of energy use should include energy use during electrification.

In the first scenario, the value to DNOs is increased because the EE retrofit targets high value / ceiling prices properties, or otherwise, homes that are electrically heated. According to National Grid Electricity Distribution, the network value of energy efficiency measures, such as thermal insulation, in these homes can be £1,000 or more. However, this is also highly dependent on homes’ energy use profile and local network conditions:

- Installation of EE in areas with severe network constraints realises approximately seven times more value than in areas with moderate constraints.
- EE delivers 5 times more value in zones with chronic network constraints (5 years) than region with short term (1 year) constraints.
- Value of EE varies with heating type in homes with electrified heating, with heat pumps or conventional electric heating delivering 3 times more value than storage heaters.

The size of home and type of EE measure are secondary factors, with cavity wall insulation and solar PV having the most significant effect, but significantly less than the severity of network constraints. Geography of households matter too, as EE provides higher value to the grid in areas with a high population density and high deprivation. This is further supported by the fact that network constraints tend to be a local phenomenon and can be addressed only from within precisely defined area.

AgilityEco's report proposed an Alternative Investment Strategy (AIS), which promotes the diversion of budget allocated to load-related network upgrade schemes in local schemes that improve energy efficiency (AgilityEco, 2015). This challenges current network planning processes, and its viability depends on two main factors:

1. Size of the Prize:
    a. This was an analysis of past and future expenditure to understand what proportion of the grid's core investment budget could be spent towards residential EE, as an alternative to increasing capacity of network.
    b. The potential prize added up to £5.2m per year, or 1.4% of the capital investment of the Northern PowerGrid. This was the maximum that a DNO (along with customer driven reinforcement) could spent per year in EE, which was significant.
    c. However, investment in network reinforcement at low voltage is particularly reactive and the budget, like any forecast, is likely to vary in order to adapt to changing external factors.
    d. The impact of the recession and of energy efficiency improvements over the period has been to slow down the rate of growth, leading Northern Powergrid to assume a 0.5% per annum growth in peak demand.
    e. If demand rises more slowly than projected, whether due to slower regional or national economic or population growth, successful energy efficiency measures, slower take-up of low-carbon, and other electricity dependent technologies such as electric cars then there is less pressure to invest in network reinforcement, and hence less availability to switch to specific energy demand reduction alternatives.
    f. However, faster demand from higher economic or population growth, less successful energy efficiency measures, or faster take-up of low-carbon, and other electricity dependent technology, will add to the pressure to reinforce the network and mean that more investment is potentially available to shift to AIS. This is likely to be the case moving forward, and thus, increases the value of EE to the grid.
2. Economic feasibility:
    a. This was the cost effectiveness of AIS (in £ per kW of winter peak demand reduction) compared to that of network investments (in £ per kW of winter peak capacity created) to address the question: "of the proportion of the budget that was categorised as likely to be suitable for AIS, how competitive is investment in local energy efficiency likely to be compared to conventional network reinforcement?"
    a. About 14% (by cost) of 77 network reinforcement projects in Yorkshire have a required cost effectiveness of £500 per kW or above. About 10% (by cost) of network reinforcement projects in this sample have a cost effectiveness of £1,000 per kW or above – noting however that this is just four costly projects.
    b. To deliver AIS with the scale and reliability required to make a meaningful contribution, it makes sense to consider energy efficiency choices in order, namely investment in:

    - More efficient space heating or insulation in electrically heated homes; These are key at low voltage level where high impact per home is needed to deliver on a scale that benefits the network.
    - More efficient water heating in electrically heated homes.
    - More efficient electricity usage overall, or more efficient appliances and lighting.
  c. Certain measures, such as low energy lighting and water heating time switching, were identified as competitive on cost-effectiveness grounds for AIS without further subsidy. However, projects involving low energy lighting alone are unlikely to deliver sufficient peak winter demand reduction to be an alternative for low voltage reinforcement projects, which affect small numbers of households.
  d. This analysis did not take into account issues such as impact of 'diversity' or rate of take-up of low carbon grid technologies.

In addition to this, a variety of government schemes provide subsidy for EE measures, which can supplement the potential AIS support and enable measures to compete with conventional reinforcement expenditure – in these cases AIS could act as 'gap-funding' to fill gap for projects that can't only be supported by government funding.

Challenges:

In order to derive impactful value of energy efficiency retrofits to the UK electric grid, high users of electricity need to be targeted first, as this will lead to a significant enough peak demand reduction for DNOs to notice. However, this argument presents two major barriers:

1. Electricity network operators have a social obligation to prevent fuel poverty and improve the quality of life of vulnerable households. By prioritising households that already use less electricity due to cost, for the installation of EE measures, however, means that the quantifiable value of implementing EE retrofits in these households is significantly reduced as impacts on peak demand reduction will be minimal to the grid overall.
2. Implementing EE retrofit measures in homes can result in homeowners 'comfort taking', which can offset any peak load reduction from the efficiency gains and reduce the reliability and predictability of EE measures in the long term. This can create situations in which reinforcements are needed at a later stage. This can occur because of:
   a. An income effect, e.g. a reduction in electricity bills from one source means that there is more to spend on other consumption which uses more electricity;
   b. A price effect, e.g. a reduction in electrical heating costs means that households feel able to heat their home to a higher temperature, taking the benefit as more heat rather than lower bills.

Ofgem allows for rebound effects in the residential sector by assuming that 15% of the energy saved by insulation is "taken back" by improved comfort in the form of higher temperatures. This figure is assumed to be 40% for people living in fuel poverty.

Renewable Curtailment: Research suggests that phasing out lignite and installing more capacity for renewables will lead to a higher probability of over generation during some hours of day and lack of adequate capacity during others. Consequently, the value of an EE retrofit project decreases when its impact to the grid does not align with the fluctuations of power demand at the aggregated level. For example, during periods of renewable over-generation when power demand is low, but electricity production is high, EE measures that permanently reduce the load will lead to further renewable curtailment. On the other hand, EE measures that can be used to dynamically shift the load, through harnessing customer demand profiles, can prompt DNOs to provision flexibility services when demand should be increased during times of high renewable generation, and decreased during times of low renewable generation. This demonstrates the importance that the role of flexibility in the value stacking of EE projects to the grid.

Another reason why an EE project's value might decrease is due to lowering the utilization of power plants, which results in:

- Reduction of probability of capacity deficit;
- Reduction of needed amount of electricity storage;
- Reduction of utilization factor of technology clusters that are not in phase-out stage. In other words, if an EE project reduces utilization factor of a group of power plants without completely displacing them, it actually increases the total cost of the power system's operation.

Moreover, many network reinforcement investments are timed to 'piggyback' on end-of-life network asset replacements, so the incremental cost of providing extra capacity is sometimes only a minor part of the overall cost. In addition to this, reinforcement and customer-driven investment itself is limited and represents only a small part of grid's total costs. Furthermore, the reinforcement budget is underpinned by establishment methodology which balances grid's security of supply obligations with financial efficiency imperatives. Therefore, EE must be the most economically viable solution to be considered as an alternative to network reinforcement.

The final challenge is that the value of EE is too insignificant to be worth the hassle for DNO consideration. This in reinforced by the low Ceiling Price determined from the DEFENDER project. The Ceiling Price was identified as the maximum amount that a DNO would be willing to pay for EE intervention without costs outweighing the benefits and was generally under £100 per dwelling, which was relatively low in comparison to the cost of the EE interventions that made a significant difference to peak demand. Thus, focusing on interventions associated with the Ceiling Price are not the most economic course of action.

RetroMeter will need to address and tackle these challenges in detail in the next phase of the project to demonstrate the overall value of this project to the grid.

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