A framework for selection and integration of packages of measures for low carbon dwellings

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Abstract

The residential sector produces more than 25% of the UK's greenhouse gas emissions and, according to the IPCC 4th Assessment Report, has one of the greatest potentials for economic mitigation action. UK policy initiatives such as the Code for Sustainable Homes and the Carbon Emissions Reduction Target (CERT) have been developed for the sector. The Code for Sustainable Homes will require all new dwellings from 2016 to achieve "zero carbon" status, whilst CERT motivates efficiency and some microgeneration measures in the retrofit arena. This paper presents relevant developments in UK energy policy, and outlines an optimisation-based framework for selection and integrated control of appropriate suites of technologies to meet low carbon targets in the residential sector. The framework will develop and consider factors such as technical characterisation, stakeholder rationale, spatial distribution/resolution of measures and policy, and how policy intervention can be modelled effectively. It will enable timely analysis relevant to technology developers, construction and refurbishment industries, landlords, DNOs, suppliers, and policy makers.

Introduction

In the UK the Committee on Climate Change, CCC (2008), suggested that greenhouse gas emissions should be reduced by 80% below 1990 levels by 2050. This challenging target, which became legally binding in the Climate Change Act (HM Government (2008a)), is anticipated to be realised by rapid decarbonisation of electricity generation combined with action in the built environment, industry and transport sectors. The CCC report specifically identified the residential sector as an area where substantial carbon dioxide (CO_2) reduction can be made at low or negative cost. Energy efficiency measures and behavioural changes where recognised as having the largest cost-effective potential, and microgeneration of electricity and heat were also acknowledged to have good potential, although at higher cost.

It has been shown in the 40% House project Boardman et al. (2005) that in order to achieve an overall 60% CO_2 reduction by 2050 for the residential sector, many demand-side measures such as building fabric changes, efficient lighting and appliances, improved control systems, and behavioural changes are required. Importantly, in addition to these measures, microgeneration is required. Indeed in order to achieve the targets one or more microgeneration technologies operating in each dwelling will be needed. Important relationships between available technologies, efficiency actions, residential demand, economics, and environmental outcomes exist. Given these interactions, intelligent selection and integration of efficiency measures and microgeneration can maximise emissions reduction for the sector at minimum private and public cost.

There is no existing research that systematically identifies the best "packages of efficiency measures and microgeneration technologies", based on stakeholder motivations and policy options and in context of developments in the broader energy system. This short paper outlines a framework to that can help fill this gap. It will enable exploration of the relevant packages of measures and competing options (such as community heating and more centralised approaches) and consider the problem in the context of broader energy system change. Importantly, it will explicitly reflect stakeholder business cases and policy options into the assessment framework, enabling investigation of impacts on stakeholders of mass market changes, and scrutiny of the policy instruments that can best address barriers.

Background

There are a broad range of factors stimulating transformation of residential energy supply and demand. These relate primarily to rapidly emerging policy instruments, availability of new technologies, and new business models being applied to the sector.

On the policy front (in the UK), several new or altered instruments have been or will be introduced. The Code for Sustainable Homes, as discussed in CLG (2006), will require all new dwellings to be net zero carbon from 2016, with graduated strengthening of the energy/CO_2-related aspects of the building regulations between now and then to arrive at this target. This is probably the most exacting proposed policy instrument, and there is understandable doubt as to whether the skills and workforce can be in place in time to meet its requirements. For existing dwellings, the Carbon Emissions Reduction Target (CERT), implemented via HM Government (2008b) is probably the most important instrument. It requires energy suppliers (i.e. the retail element of the liberalised market) to install a number of "qualifying actions", each of which has a deemed CO_2 reduction, which cumulatively must add to a specified target. It offers leeway regarding which actions are installed, and actions and target quantities may be traded amongst parties, resulting in an arguably economically-efficient solution. Other policy instruments are also evident; value added tax (VAT) relief from 15% (previously 17.5%) to 5% on energy saving items (e.g. HM Government (2005)), a grant scheme for owner/occupiers installing microgeneration (HM Government (no date)), exemption from income tax on revenue from export of electricity (HM Government (2007a)), exemption from stamp duty for dwellings that meet a zero carbon standard (HM Government (2007b)), and suspension of the 28-day rule[1] to facilitate energy service type approaches. Most recently, the Energy Act (HM Government (2008c)) has set out a "feed-in tariff" type reward mechanism for renewable and low-carbon microgeneration to incentivise good performance of these technologies.

A further driver is the relatively recent emergence of a variety of promising technologies, or improvements in existing ones. Among these, the materialisation of relatively affordable microgeneration systems such as micro-wind, micro-CHP, and biomass boilers has created a potential market where none existed previously. Availability of these technologies creates opportunities to reduce the CO_2 footprint of the residential sector, but also complicates the analysis of energy-economic-environmental performance of buildings.

Finally, the appearance of new or altered business models, such as Energy Service Companies (ESCo), has the potential to propel new technologies into the residential sector, or enable better uptake of existing ones. Whilst a variety of models for such companies exist, one approach is to offer the dwelling owner/occupier supply of energy services to their dwelling for the same cost as existing supply, install energy saving and/or microgeneration measures, and recover capital expenditure via the difference between the initial and the reduced energy bills. These business models are designed to circumvent information-related barriers faced by typical owner/occupiers by applying more professional and structured analyses to energy investment and possibly some operational decisions. However, these new business models such as ESCos are not yet widespread, and the conventional generation transmission-distribution-supply chain dominates. However, radical change in the residential sector may influence these conventional business models substantially, creating a need for incumbents to adapt their strategies or commercial offerings.

Given interactions between the raft of issues discussed above it is clear that a great deal of uncertainty exists in the sector, ranging from a lack of information and strategies to adhere to proposed regulations, through to lack of confidence that the overall direction has a chance of success. Without an integrating base of evidence and research to tackle these uncertainties and help shape policy, it is likely that commercial developments will be fragmented and will fail to contribute effectively to overall policy objectives. The remainder of this article outlines a modelling framework designed to help fill this gap by informing stakeholders regarding promising transformation pathways for the residential sector, and make clear the impacts of, and policy drivers for, sweeping change in the residential sector.

Aims of a Modelling Framework

There is a need for research to create a robust and systematic analysis framework to provide insight regarding the most effective pathways to deliver a low carbon residential sector at low private and societal cost. Framed by longer term emissions reduction targets, this framework will help to identify technology options and combinations, stakeholder business cases and motivations, and appropriate supporting policy and regulation that are relevant for the next two decades. Outputs should not only be technically relevant, but also be suitable for interpretation by a non-technical audience such as commercialisation stakeholders and policy makers. It will build upon previous high level modelling efforts by developing a more stakeholder-led approach bringing state-of-the-art optimisation and building simulation approaches to explicitly link technical, commercial and political concerns to low carbon futures in the residential sector. Figure 1 displays the three basic input themes required for the framework.

Essentially it is desired to cast the key issues surrounding residential sector energy futures in a holistic manner to enable whole-system scenario analyses, whilst simultaneously retaining granularity of residential demand and appreciating potentially complex interactions between various measures in individual dwellings.

1. The 28-day rule was a regulation that enabled residential customers to switch energy suppliers with 28 days notice. It was designed to encourage competition between suppliers, but was seen as an impediment to energy service approaches where purchase of capital equipment within a dwelling without guaranteed access to the benefitting customer could entail increased risk.

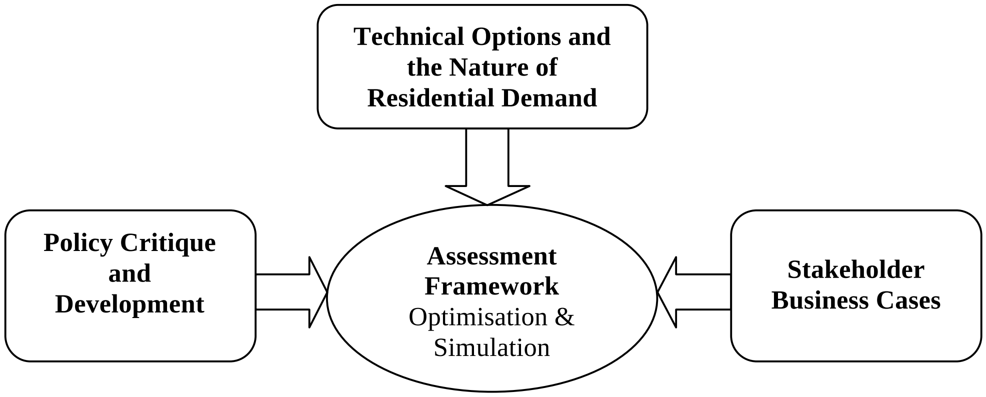

Figure 1. Basic Inputs to Assessment Framework. Policy instrument structures and stakeholder business cases are explicitly defined in the framework.

TECHNICAL CREDIBILITY

A cornerstone of the framework is technical credibility, which is clearly required for constructive outputs for technology developers. Indeed overall energy, economic and environmental outcomes would not be accurate without realistic representation of efficiency measures, microgeneration technologies, and their interactions within a dwelling. Technical credibility of the framework must therefore be ensured by enhancement and application of established building simulation techniques, and robust linkage of these with the overarching optimisation methods. Use of a dynamic model of buildings physics enables the interactions between the building, environment, occupants and its energy systems to be properly accounted for, particularly in the sense that thermal demand is endogenous to credible examples of simulation.

STAKEHOLDER BUSINESS CASES

As discussed above, it is of interest to consider the impact of radical change in residential sector energy provision on the business cases of existing energy system stakeholders, and to examine the potential of new business models. When integrated explicitly into the assessment framework, feedback between policy, technology and business strategies can be examined. A list of important stakeholders includes: energy suppliers, distribution network operators (DNO), policy makers (including national, regional, and local levels), and private investor or dwelling occupier. Each of these stakeholders has different and possibly conflicting motivations, and it is necessary to understand these interactions to enable appropriate reflection in the assessment framework. Sources of conflict may then be identified, feeding into possible regulatory change or alteration of business models. Commercial relevance is a key element of the analysis given the scale of change required to meet low carbon targets, and understandable resistance from stakeholders with currently-functioning business models.

POLICY AND REGULATION

The final element in assessment and supporting understanding is critique of current and proposed policy supporting achievement of low carbon targets for the residential sector. A variety of policy approaches exist in the OECD, and a critical review of these can form the basis for those that are incorporated into the framework. Each class of policy instruments at work in the residential sector, including building envelope and appliance regulation, taxation, low interest loans, grants, production-based incentives and cap-and-trade arrangements can be amalgamated into the assessment through characterisation of financial or other incentive created. Methods of delivery of incentives, such as government engagement with each echelon of the energy supply chain, and potential for engagement with the demand-side (i.e. consumption-based models rather than production-based models) can also be considered. The relevance of each policy intervention to a specific country can then be considered.

Energy System Context

The broader energy system has a marked influence on the relative economics and environmental impacts of alternative means of providing residential energy, such as microgeneration. This is because the broader energy system forms the reference against which packages of measures should be evaluated. The complicating aspect of such evaluations lies in the fact that actions on the demand side (including microgeneration, which is often considered to be a demand side action from a conventional energy system view) have an influence on the margin of centralised energy provision rather than on the average. Furthermore, these marginal effects need to be considered in the context of large irreversible investment in centralised energy infrastructure, and in terms of their longevity, before defensible assessment can be made.

The commonly cited example of a marginal impact is that of a small reduction in electricity demand causing one large centralised power station to modulate its output slightly. The CO_2 emissions impact of the demand reduction clearly depends on which power station modulated its output. In a system sense this power station is the marginal generator, and the CO_2 emissions reduction is dependent on its fuel type and performance. However, further issues rarely discussed in any detail also bear keenly on this outcome. Perhaps foremost among these are the nature and performance of notional future power stations. If a large number of demand-side reductions accumulate and result in this next generation of plant build being deferred due to lack of demand, then the emissions footprint of this future plant must also be important in assessing the relevant emissions credit to award to the demand side measure.

The recent Climate Change Committee Report (HM Government (2008a)) has outlined ambitious changes required in centralised electricity generation in the UK. These indicate that grid-average CO_2 emissions rates should be reduced to of the order of 0.3 kg CO_2/kWh over the next two decades. If these recommendations are implemented, radical change will be required, and the baseline against which demand side actions should be measured will become an elusive target, further necessitating robust research in this area.

Sound research into the influence of packages of measures in the residential sector must therefore incorporate a good understanding of the uncertainties related to the broader energy system. Where appropriate, marginal impacts (both economic and environmental) can be modelled via predictions of generator response for the near term, systematic energy trading impacts for the medium term, and planned future plant build for the long term. The impact of uncertainties in each of the relevant temporal and institutional frames should also be well understood, resulting in assessment that is risk-aware rather than deterministic.

Metrics of Interest

A vast array of metrics can be formulated to assess energy use. These predominantly relate to economics, the environment, and energy security. Each of these can be reflected into metrics for assessment in the proposed modelling framework, and are discussed briefly below with respect to residential energy supply and demand.

- Economics should be considered from the perspective of each stakeholder in the energy system in order to obtain an understanding of the impact of large scale change. A shortlist of these stakeholders includes:
  - Dwelling owner/occupier, who can make investment and operational decisions. This stakeholder is arguably the most difficult to characterise in a modelling framework, where social, cultural, socio-economic and many other factors play a role.
  - Energy Suppliers. The retail element of the liberalised energy market is currently the focus of many policy interventions because they conventionally have the most direct contact with the dwelling occupier, and are the economic intermediary between generators and customers. Suppliers' business models may need to change from mainly just delivering energy units to premises to delivering energy services or low carbon energy equipment if low carbon targets are to be achieved.
  - Distribution Network Operators (DNOs) are important stakeholders for energy system change, because they stand to lose or gain substantially if the requirement to deliver units of electricity from generator to customers alters drastically. DNOs recover the lion's share of their allowable revenue (i.e. they are regulated natural monopolies in the UK) via charges per kWh transported. If substantial microgeneration were to meet the majority of onsite loads, less electricity would be transported, with appreciable impact on the DNOs business case.
  - Generators. Likewise with DNOs, radical reduction of demand will impact upon the business case of centralised power stations. New plant build may be deferred, or in extreme cases plant could be mothballed.
  - Technology developers can also benefit from appropriate economic characterisations, where the target production cost of measures can be explored, and the potential economic benefit (and technical requirements) of integration of multiple systems can be examined.
- Environmental impacts.
  - Greenhouse gases, particularly CO_2 and CH_4 (the dominant compound in natural gas) are an obvious choice of metric and are the subject of a number of government targets, aspirations, and laws in various countries. The ability of actions in the residential sector to help meet these targets should be assessed with sensitivity to interactions with the broader energy system, as discussed above.
  - Further environmental parameters, many related to human health, have also been recognised as highly important in residential sector energy matters. For example, particulate matter, and nitrous and sulphur oxides may be detriment to health, while thermal comfort may improve it.
- Energy security.
  - Primary energy consumption.
  - Diversity of fuels and fuel sources to examine exposure to geopolitical instability and to diversify a countries portfolio of fuels and subsequent economic exposure.
  - Geographical distribution of energy infrastructure may improve the resilience of a country's supply to localised problems.

Importantly, the uncertainties inherent in system change require appropriate depiction in order to produce defensible assessment of the metrics presented above. Techniques such as Monte Carlo analysis can be applied to enable each metric to be assessed as a probability distribution rather than a single deterministic value. Correspondingly, an array of sets of solutions can be identified by high level optimisation modelling, rather than a single deterministic set.

Conclusion

This paper has briefly discussed the factors that could bring about change in residential sector energy supply and demand. These relate to a set of policy drivers, and technology availability, and the emergence of new business models. Given that these drivers indicate substantial change is imminent for the residential sector, it is timely to build a modelling framework to explore questions relevant to how transformation may be achieved in a manner that is acceptable to consumer, commercial, and political stakeholders.

The challenging magnitude of medium and long term emissions reduction required for climate stabilisation suggests that it is probable that the energy system as a whole will change radically over coming decades. The residential sector, which is responsible for a sizeable portion of most country's emissions, will likely also evolve rapidly over this time period. It is therefore timely to consider the best transformational pathways for this sector that can meet the requirements of relevant stakeholders, and to do this in the context of broader energy system change. To aid this exploration, a modelling framework is required that is capable of exploring broad sectoral trends whilst still respecting the technical intricacies of residential demand and interactions between the various demand-side technologies such as microgeneration. Indeed detailed building simulation is required, overarched by the higher-level optimisation, to identify and investigate packages of measures that can meet targets in a commercially and politically sensible manner, and to enable investigation of feedbacks between technical, commercial and policy interventions. Complementing this activity, the likely changes in the broader energy system must also be mapped. Given the radical changes suggested for the centralised electricity system in the recent Climate Change Committee report in the UK, this point is particularly relevant. Finally, the entire framework should be built in a manner that is sensitive to uncertainties, enabling probabilistic representation of results of interest rather than single deterministic conclusions.

Overall, it is clear that the residential sector faces a time of upheaval, driven by radical changes in the building regulations in many countries and pushed forward by a wide array of further policy instruments. Appropriate tools are required to underpin commercial and political developments, creating better understanding regarding how greenhouse gas reduction targets can be achieved. These tools need to represent the options in a technically credible manner, but avoid dictating superlative transformational pathways. Ultimately they could enable technology developers, policy makers and various commercial stakeholders (to name a few) to better formulate strategy in coming decades.

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