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POSTNOTE

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Assessing Energy Efficiency

Climate change, finite supplies of fossil fuels, and rising and volatile fuel prices all drive the need to improve energy efficiency. This POSTnote examines definitions of energy efficiency, looks at methods to measure and verify achieved energy savings and summarises UK and EU polices to promote energy efficiency.

Overview

- Improving energy efficiency means using less energy to produce the same output or service. Output is measured either in physical units, such as energy quantities, or in economic units, such as GDP.
- Energy efficiency improvements face technical, economic and behavioural barriers that can be influenced by policy.
- The UK's residential energy efficiency policy is changing in late 2012 to the Green Deal and a new Energy Company Obligation.
- The EU is currently debating the Energy Efficiency Directive, including how energy efficiency will be measured.
- When interpreting energy savings and the effect of energy efficiency policy, wider issues such as international impacts, the accounting procedures used and behavioural responses need consideration.

Background

Cost-effective energy efficiency improvements can:

- support commercial and industrial competitiveness through cost reduction;
- reduce fuel poverty by increasing fuel efficiency (a household is in fuel poverty when its energy bills are greater than 10% of household income);
- improve energy security (POSTnote 399) by reducing energy consumption;
- reduce energy related carbon dioxide (CO_2) emissions.

Numerous policies seek to improve energy efficiency. At the European level, the 2008 Climate and Energy Package has a target of a 20% reduction in annual primary energy consumption by 2020 compared with "business-as-usual" projections. Currently only a 10% reduction is predicted and meeting the 20% target is therefore the focus of the proposed Energy Efficiency Directive (Box 1). At a national level, the Energy Act 2011 introduced the Green Deal, a finance framework that aims to improve residential energy efficiency. The Act includes provisions such that from 2016, private residential landlords will be unable to refuse a tenants' reasonable request for consent to energy efficiency improvements, as long as a finance package such as the Green Deal is available.[1] DECC recently set up the Energy Efficiency Deployment Office to "*drive a step change in energy efficiency*".[2] It has a board composed of directors from across government departments and has the objective of developing a long-term UK energy efficiency strategy.

Box 1. EU Energy Efficiency Policies

- The proposed **Energy Efficiency Directive** aims to meet the EU's 20% reduction target in primary energy consumption. There is currently intense debate on whether the Directive should have binding targets and whether the targets should be in terms of absolute energy savings or in terms of energy use per unit of GDP (a quantity known as energy intensity, discussed later). The 1st reading agreement should be concluded by the end of June 2012.
- The **EU Emissions Trading System** (EU ETS) is a "cap and trade" scheme for organisations that are large emitters of greenhouse gases (GHG). Allowances are allocated to, purchased by or traded between the organisations whose emissions are limited by the cap (POSTnote 354 and 403). The scheme thus puts a price on GHG emissions and aims to encourage emissions reductions, including through energy efficiency improvements.
- The **Eco-design for Energy-using Products Directive** sets EU-wide efficiency standards for a number of product areas, notably motors, refrigerators, lighting and boiler. The energy efficiency classes are A to G and are displayed at the point of sale.

Defining Energy Efficiency

Energy efficiency is the ratio of the desired output to the total energy input. Improving energy efficiency therefore means using less energy to produce the same desired output.[3] Energy inputs are typically measured in energy units, such as joules (J) or kilowatt-hours (kWh), while outputs are measured as one of the following:

- **Energy units**. For example, the output of a power station can be described by the joules of electricity it produces; the output of a household boiler by joules of heat. These outputs can be compared with the fuel input to calculate an energy efficiency. However, care needs to be taken when interpreting and comparing energy efficiencies, because they do not give a complete picture of thermodynamic performance.[4]
- **Other physical units**. The output of a factory can be described as the number of products produced; the output of a car in terms of the distance it travels.
- **Economic units**. The output of an economy is often measured in terms of gross domestic product (GDP), and its efficiency in terms of energy use per unit of GDP. This is referred to as *energy intensity*. Historical trends show that UK energy intensity has decreased at approximately 2-3% per year since the 1970s (Box 2).

Box 2. Trend in UK Energy Intensity

Since the 1970s the UK's energy intensity has decreased (Figure 1) because GDP has increased while energy use has remained relatively steady. This is due to improvements in energy efficiency and a shift from high-energy intensity manufacturing to the low-energy intensity service industry. Some argue that the decrease in energy intensity implies a decoupling of GDP from energy consumption, though this is the subject of ongoing debate.[5] This debate is important because, if growth is not becoming decoupled from energy consumption it will be particularly difficult to meet the UK's GHG emissions reduction targets under the Climate Change Act 2008.[5]

Figure 1. UK Energy Intensity and Final Energy Consumption

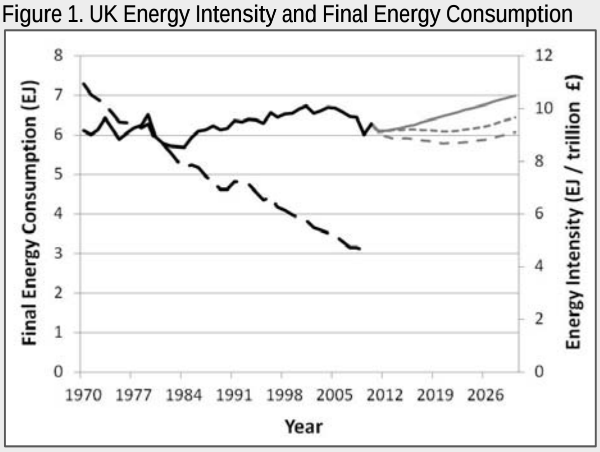

Figure Notes: Historical energy intensity is shown as a black dashed line, where 1EJ is equivalent to 10^{18} J.[6] Final energy consumption – that is, the energy delivered commercially to consumers – is shown by a black solid line,[7] along with DECC's upper (grey dotted line), lower (grey dashed line) and "business-as-usual" (grey solid line) scenarios of future final consumption.[7] The "business-as-usual" scenario has mid-range price and growth assumptions and only includes policies that existed before the previous Government's 2009 *Low Carbon Transition Plan.*

Potential for Energy Efficiency Improvements

There will always be a limit to improvements in energy efficiency. For example, thermodynamic laws dictate that the heat produced when burning coal, for example, could never be converted entirely into electricity; there will always be some wastage. In fact, given typical operating conditions, the maximum theoretical efficiency for existing coal-fired power stations is between 50 and 60 percent. This theoretical figure can be compared with the current energy efficiency of a process to indicate the theoretical potential for improvement (Figure 2).

Figure 2. Illustrating the Potential to Improve Efficiency

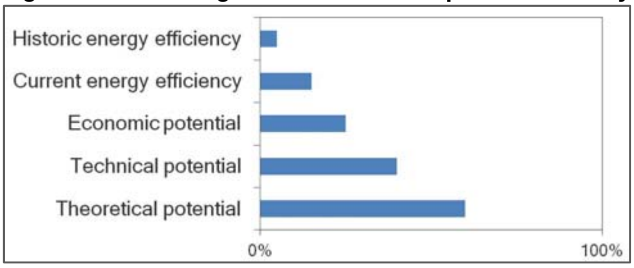

Figure Notes: This figure is illustrative only; the exact potentials for improving energy efficiency will vary on a case by case basis.

In practice, improvements are limited by what is technically and economically achievable, also illustrated by Figure 2. The potential for technical and economic efficiency improvements change with time as technology develops and energy prices change. Both of these can be influenced by policy, which can also influence the variety of barriers that tend to limit the uptake of economic energy efficiency improvements (Box 3). Studies have shown that the sectors with the greatest theoretical scope for energy savings are buildings, electricity generation and transport; industry is relatively energy efficient by comparison.[4,8]

Box 3. Barriers to Economic Energy Efficiency Improvements

The barriers that prevent the adoption of cost-effective measures can be broadly categorised as[9]:

- Behaviour and motivation. These include the hassle factor of investigating and installing energy efficiency measures. (Energy behaviour change will be covered in a subsequent POSTnote.)
- Financial. Consumers are often economically irrational in that they opt for low efficiency products, with lower upfront costs even though the lifetime costs are typically lower for more energy efficient products. Businesses have to choose between spending on energy efficiency measures and growth projects. The former does not have the same level of appeal, and although the latter may have greater risk, businesses generally understand it better.
- Misaligned incentives. These exist wherever two or more parties are not equally incentivised to act. For example, split-incentives exist for landlords (who would not directly receive the benefit of reduced energy bills) and tenants (who will not benefit from the lifetime benefits of reduced energy bills as they might leave).
- Hidden costs. These include the human resources needed to find and implement energy efficiency measures, and the decision-making processes of businesses (which can be altered by championing energy efficient and sustainable practices). Such factors are important but often hard to quantify, making them difficult to evaluate in decision-making.

Quantifying Energy Savings

It is important to verify or estimate the energy savings achieved by a particular intervention. In order to quantify the energy saved, the energy used after an intervention is compared with a *baseline*, which is the amount of energy that would have otherwise been used. This is calculated by:

- **Measuring the baseline directly**, by quantifying the energy used by a building or business before an energy efficiency improvement has been implemented. This allows subsequent energy use to be put in context (and is used in the CRC Energy Efficiency Scheme, discussed later). A more accurate method is to adjust the baseline to account for other factors that cause energy use to deviate from the baseline year, such as weather and site occupancy (Figure 3). The RE:FIT program, which aims to retrofit over 2000 public buildings in London with energy efficiency equipment by 2025, uses the adjusted baseline method to fund investment in energy efficiency improvements by providing investors with a quantifiable return.
- **Control group comparison,** for example, the change in energy consumption of 1000 households after a particular efficiency improvement is compared with 1000 statistically similar households who did not implement that improvement. This method requires a large database of statistical records in order to validate the savings. It is typically used when it is not possible to measure the baseline directly.
- **Deeming,** where the energy saved is measured or modelled for a single property, and then assumed to be the same across all properties considered. This is the simplest estimation process and can only be considered accurate if the measure is proven to actually deliver the savings estimated, for example through spot checks. Deeming is currently used to assess the savings in several residential energy efficiency policies and is proposed for use in the Green Deal.

Figure 3. Actual energy reduction from base line[10]

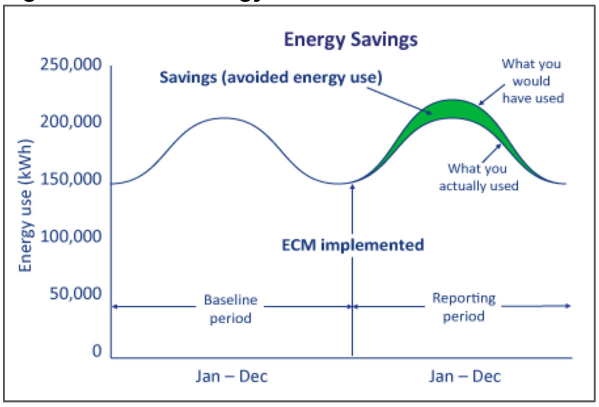

Figure Notes: ECM = energy conservation measure

UK Policy

The UK has several policies that use incentives, taxation or regulation to improve energy efficiency across the residential and non-residential sectors of the economy.[11] DECC estimates that these policies will save approximately a total of 7 to 12 EJ between 2010 and 2030, compared with a "business-as-usual" scenario without those policies (Figure 1).

Residential Policies

The Carbon Emissions Reduction Target (CERT) and the Community Energy Savings Program (CESP)

CERT and CESP are energy company obligations that will end later this year. CERT requires all domestic energy suppliers with more than 250,000 customers to make savings in the amount of CO_2 emitted by householders. CESP targets households across Great Britain in areas of low income, to improve energy efficiency standards and reduce fuel bills. A significant focus of CERT and CESP is reducing energy demand, for example, by increasing levels of insulation. The contributions are expressed as the reduction in CO_2 emissions over the estimated lifetime of the energy efficiency measure, which is, for example, 36 years for solid wall insulation.[12]

Warm Front Scheme

The Warm Front scheme started in 2000 and ends in 2012/13 with no direct replacement. It is known as the Home Energy Efficiency Scheme in Wales and the Energy Assistance Package in Scotland. These schemes address the Government's obligation to eliminate fuel poverty by 2016 (2018 in Wales). They provide grants for heating and insulation and have helped over 2 million households.[13]

The Green Deal

The Green Deal will start in the Autumn of 2012 and will use accredited advisors to provide recommendations to customers on how to improve the energy efficiency of their buildings. It will also enable energy customers to receive finance to fund the measures, which are repaid via the energy bill of the property rather than directly by the individual. To be eligible for the Green Deal the efficiency improvement must meet the '*Golden Rule'*, which states that the cost of the improvement must not exceed the savings on the energy bill.

The Energy Company Obligation (ECO)

The aim of the new ECO is to help alleviate fuel poverty and subsidise expensive but still cost-effective energy efficiency measures. ECO is split between a carbon saving obligation, which focuses on community schemes and installing solid wall insulation, and an affordable warmth target, which focuses on the vulnerable and fuel poor.[14] The targets are expressed in annual CO_2 savings. Consultation on both ECO and the Green Deal ended in January 2012[15,16] and the surrounding debate is summarised in a House of Commons Library standard note.[14]

Product Standards

Examples of product standards include eco labels and minimum environmental performance standards. The Eco-Design Framework Directive classifies mandatory minimum standards (Box 1) which are put into UK law by the Eco-Design for Energy Related Products Regulations 2010. Other labels are voluntary, for example, the Energy Saving

Trust 'Energy Saving Recommended' or the EU Ecolabel that can be displayed by qualifying products.

Non-Residential Policies

Climate Change Levy (CCL)

For the non-residential sector (excluding charities) the CCL applies, which is a tax on the supply of specified energy products for use for lighting, heating and power. Energy intensive industries can obtain a discount of 65% (due to increase to 80% from April 2013) on the CCL through Climate Change Agreements. These encourage energy savings through voluntary carbon reduction agreements Recently, there has been a consultation on adapting the CCL to include a Carbon Price Floor (see POSTnote 403).

CRC Energy Efficiency Scheme

The CRC Energy Efficiency Scheme (formerly the Carbon Reduction Commitment, which started in April 2010), applies to large organisations in the public sector (e.g. universities and hospitals) and private sector (e.g. supermarket chains and commercial offices). The organisations covered by the CRC use more than 20 TJ (6 GWh) of electricity per year and are not covered by the EU ETS (Box 1) or Climate Change Agreements. The CRC primarily aims to improve energy efficiency through a range of reputational, behavioural and financial drivers. In the 2012 Budget, the Chancellor of the Exchequer suggested that the CRC might be replaced 'with an alternative environmental tax' and DECC is currently consulting on simplifying this scheme.

Interpreting Energy Savings

Several considerations need to be taken into account when interpreting energy savings and the effect of an energy efficiency policy. These include system boundaries, embodied energy, and rebound effects.

System Boundaries

The system boundary refers to the number of processes being analysed for their energy efficiency. A small boundary is a single process (e.g. a factory, power plant or utility). A more complete analysis extends this boundary to include other processes (e.g. resource extraction, processing and/or transmission). Larger boundaries provide a more accurate idea of energy use but require more data. For example, savings vary depending on whether international factors are considered. To illustrate – the Government can encourage efficiency improvements by using taxes (e.g. the Carbon Floor Price) or regulation (e.g. energy efficiency standards). However, this may lead to heavy industry leaving the country to somewhere with lower energy prices and fewer regulations. The result may be overall decreased energy consumption in the UK leading to lower carbon emissions, but higher energy demand elsewhere and potentially greater emissions globally.

Embodied Energy

Embodied energy is all the energy that was used in making a product (i.e., manufacture, distribution, use, maintenance, and disposal or recycling). It differs from operational energy, which is the energy consumed when using the product. The BRE estimated that for a three bedroom detached house with a lifetime of 60 years before refurbishment, the operational energy is typically 12-30 times larger than the embodied energy.[17] Operational energy use has been the focus of most energy efficiency policy (e.g. the Green Deal), as it is easier to measure than embodied energy. However, as operational energy efficiency increases (for example by insulating a home) the embodied energy becomes a larger proportion of the whole-life energy requirement and it will need to be considered in future policies that aim to reduce overall energy consumption.

Rebound Effects

Rebound effects are where energy efficiency improvements lead to an energy service becoming cheaper relative to other goods and services, which can lead to increased consumption. Rebound effects can therefore have positive social and economic consequences but may lead to a conflict with the goal to reduce energy use and emissions. The magnitude of rebound effects varies widely from one circumstance to another and is very challenging to measure. Currently, 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.[18] On the other hand, the direct advice to businesses provided by the Carbon Trust assumes rebound effects are negligible. Further information is required to correctly account for rebound effects in policy frameworks.[5]

Endnotes

1 DECC, 2011, *Energy Act 2011 Aide Memoire*
2 DECC, 2012, Energy Efficiency Deployment Office: Evidence Brief
3 Patterson, M. G., 1996, *Energy Policy*, 24, pp.377-90.
4 The typical approach to measuring energy efficiency treats different forms of energy as equivalent to one another, but this is often not the case. Electricity, for example, is more useful in thermodynamic terms because it can be used to provide work (e.g. drive a motor) *or* heat. Low-temperature heat from a household boiler, meanwhile, can only be used for heating purposes. These thermodynamic differences are quantified by the technique of *exergy analysis*, which provides a more rigorous assessment of efficiency. Exergy efficiencies for the UK are available in: Hammond GP and Stapleton AJ, 2001, *Proc. Instn Mech Engrs Part A: Journal of Power and Energy*, 215 (2), pp.141-62.
5 Sorrell, S., 2007, The Rebound Effect, UKERC.
6 DECC, 2011, Energy Consumption in the UK.
7 DECC, 2011, Updated Energy and Emissions Projections.
8 Cullen, J. M., and Allwood, J. M., 2010, *Energy*, 35, pp. 2059-69.
9 Carbon Trust, unpublished, Breaking Through: Harnessing Energy Efficiency to Cut Costs and Carbon Emissions in Business and the Public Sector.
10 EEVS Insight Ltd (www.eevs.co.uk).
11 House of Commons Library, 2012, Standard Note SN/SC/05614.
12 DECC, 2011, The Green Deal and Energy Company Obligation Impact Assessment.
13 House of Commons Library, 2012, Standard Note SN/SC/06231.
14 House of Commons Library, 2012, Standard Note SN/SC/05763.
15 UKERC, 2012, UKERC Green Deal Response.
16 ACE, 2012, Dead CERT: Framing a Sustainable Transition to the Green Deal and the Energy Company Obligation.
17 Sustainable Homes, 2000, Embodied energy in residential property development.
18 DECC, 2010, Estimated Impacts of Energy and Climate Change Policies on Energy Prices and Bills.

POST is an office of both Houses of Parliament, charged with providing independent and balanced analysis of policy issues that have a basis in science and technology. POST is grateful to Alistair McVicar for researching this briefing, to the Grantham Institute for Climate Change for funding his parliamentary fellowship, and to all contributors and reviewers. For further information on this subject, please contact the co-author, Dr. Stephen Allen. Front page image produced by Hannah McVicar.