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Measuring Energy Security

Energy security is a central aim of energy policy. In the 2010 Strategic Defence and Security Review, the government said it would strengthen delivery of energy security by "more robust reporting and monitoring". This note explores ways in which energy security may be measured for monitoring purposes.

Overview

- Threats to energy security affect either the physical supply of energy or its price.
- Measures of security include diversity of fuel supplies, spare capacity in infrastructure and exposure to increased energy costs.
- Cost-benefit analysis aims to compare the costs of security investments with the benefits of reducing the risks of disruption. It can assess only risks whose probability and potential impact are well understood.
- To address uncertainties, scenario building and stress testing can explore the resilience of possible future energy systems.
- The Energy and Climate Change Committee recommends that the government assesses a broader range of security indicators in its annual report on UK energy security.

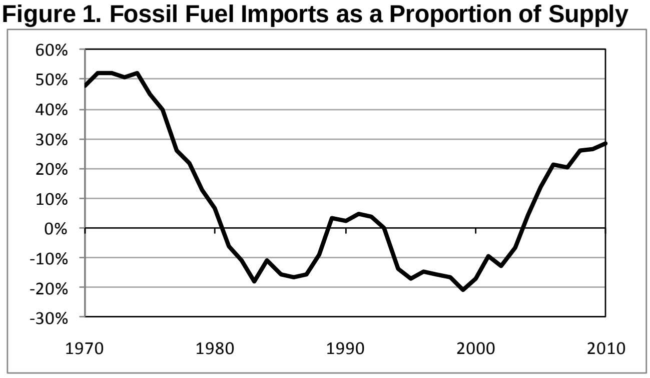
Background

Concerns over energy security are caused by either physical supply disruptions or spikes in energy prices. Both have occurred in the past, for example, the oil shocks of the 1970s, but their prevalence around the world over the last decade has caused a resurgence of concern. In the UK, two factors in particular drive current interest:

- **increasing dependence on imported fossil fuels**. As shown by Figure 1, the UK has returned to levels of import dependence not seen since the 1970s. As domestic oil and gas production is declining, this dependence is likely to increase.
- **the shift to a low carbon energy system**. The Climate Change Act (2008) and EU Renewable Energy Directive (2009) require the UK to substantially reduce greenhouse gas emissions and increase renewable energy production. These have implications for energy security. For example, as discussed later, power stations that close over the next decade will be replaced by variable or inflexible low carbon generation, bringing challenges for managing the electricity system.

Energy security is a broad concept with no agreed definition.[1] This creates difficulties for assessing and monitoring policy. For instance, the Department of Energy and Climate Change (DECC) outlines four main policy

Figure 1. Fossil Fuel Imports as a Proportion of Supply



Source: DECC, *Energy in Brief 2011*. The graph shows net import dependence across all fossil fuels; dependence varies for each fuel. In 2010, the UK imported 52% of the coal used. Gas, crude oil and refined oil are exported as well as imported. On balance, the UK was a net importer of 38% for gas and 14% for oil in 2010.

objectives for energy security:[1]

- maximise economic recovery of domestic fuel reserves
- reduce demand for energy
- ensure a well-designed market framework with a clear allocation of responsibilities, such that the necessary fuels and infrastructure are cost-effectively delivered
- influence other countries, for example by diversifying imports and supporting long term contracts.

However, the House of Commons Energy and Climate Change (ECC) Committee found it difficult to assess progress against these objectives using the government's annual security of supply report.[1,2] The committee called on the government to publish a clearer definition of energy security with a strategy for achieving it, and to analyse a broader set of indicators in the annual report. The government response to these recommendations is expected in early 2012.

Threats to Energy Security

To debate an appropriate set of indicators, the nature of the threats must be understood. As Box 1 illustrates, threats can be caused by human intervention, equipment failure, and/or extreme weather. These affect three parts of the energy system over varying timescales, as illustrated by some examples below:

- **energy resources.** Political action can disrupt supplies or cause price spikes, while the depletion of conventional oil reserves threatens long-term security.
- **infrastructure.** Bad weather can damage electricity networks, while an ineffective market may not deliver sufficient long-term investment in power plants.
- **demand.** A cold winter's day causes a surge in gas demand that can be difficult to meet.

Box 1. Examples of Energy Insecurity, 2000-2011

Supply Disruptions

- In 2000, UK oil refineries were blockaded in a protest against fuel duty, causing widespread disruption to the supply of petroleum. The government has since introduced a National Emergency Plan for Fuel, which could use powers from the Energy Act 1976 to introduce rationing in the event of future supply constraints.
- In 2000 and 2001, a combination of factors caused rolling power cuts in California that affected hundreds of thousands of people. A key factor was an ineffective market framework, which saw under-investment in power stations during preceding years and market manipulation by certain companies. Numerous unplanned outages of older generators also contributed, together with high levels of electricity demand and a rupture of a major gas pipeline.
- In 2005, a huge fire damaged the Buncefield Oil Storage Terminal in Hemel Hempstead (pictured on front page). This caused the closure of local businesses and evacuation of the surrounding area, and for two years afterwards, jet fuel rationing was imposed at Heathrow Airport during peak periods.
- In February 2006, a fire damaged the UK's largest gas storage facility, Rough. In March, the combination of a cold weather forecast and a lack of alternative gas stocks led to a quadrupling of wholesale prices in four days. (No customers went unsupplied.)

Price Increases

- After more than a decade of low oil prices ($20-40 a barrel), the 2000s saw prices increase to almost $150 a barrel in 2008. Prices then fell sharply as the global financial crisis hit, but rose again and have been volatile and above $100 since 2010. The causes of price volatility are complex, but factors include a lack of spare capacity combined with strong demand from emerging economies and various disruptions, such as that caused by the war in Libya.[3] (The high street prices of petrol and diesel depend on national taxation as well as global oil prices. Currently, 58-60% of the pump price is due to taxation. That proportion began the 1990s at a similar level but reached a peak of 85% in 1999 because of falling oil prices combined with fuel duty increases.[3])

Although much popular debate focuses on foreign risks to fuel supplies, a recent review[4] indicates that most electricity and gas "shocks" of recent decades were caused by local equipment failure or weather-related events. Oil prices have increased in response to international events, but actual UK disruptions have been caused domestically (e.g. Box 1).

Energy Security Indicators

Energy Resources

Dependence on Imported Fuels

Import dependence is sometimes seen as an indicator of reduced energy security. However, being self-sufficient in energy does not guarantee protection from domestic shocks, such as protests and accidents, or from internationally-driven price spikes (Box 1). The ECC Committee concluded that import dependence is not in itself incompatible with energy security, which can be maintained by a diversity of energy sources and suppliers.

Diversity

A more diverse energy system is less vulnerable to disruption of any one part. However, it is not always clear how an energy system may be diversified, nor how that may be measured. Options include diversifying the mixture of:

- energy resources used by an economic sector or country (e.g. Figure 2, Box 2)
- countries and/or companies supplying those resources (e.g. Figure 3, Box 2)
- technologies and infrastructure used to convert, transport and deliver energy to consumers.

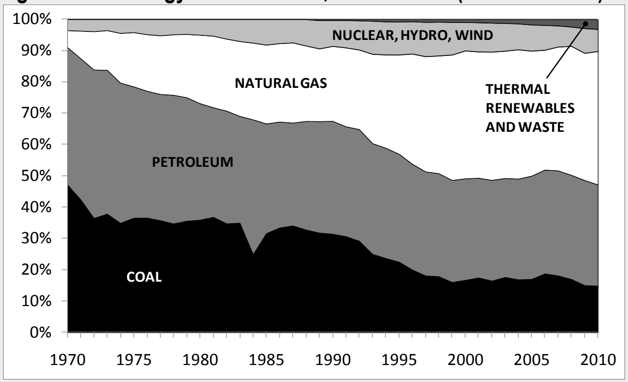
The approach taken in Box 2 is typical: the *variety* of options and the *balance* of their contributions are described.[5] Several indicators combine these aspects into a single number to quantify diversity and track its changes over time. Two such indicators are published by the government as background energy indicators[6] but are not discussed in its annual security of supply report.[2] Such indicators are somewhat arbitrary because they depend on the way that fuels and technologies are categorised. For example, distinguishing between coal and gas will yield a very different result from grouping them together as fossil fuels. Work is ongoing to address this categorisation explicitly when measuring diversity.[5,7]

Infrastructure

Redundancy in energy infrastructure makes a system less vulnerable to breakdowns and disruptions of any one part. Spare capacity comes in various forms, including fuel and electricity import infrastructure, electricity generation capacity, transmission network capacity and fuel or electricity storage facilities. The following two sub-sections outline two prominent infrastructure indicators: the electricity capacity margin and fuel storage. Delivery of energy infrastructure depends upon a skilled engineering workforce, but various observers, including the House of Lords Science and Technology Committee,[8] have expressed concern over future skills gaps in this area. Skills-related indicators are thus also relevant to energy security.

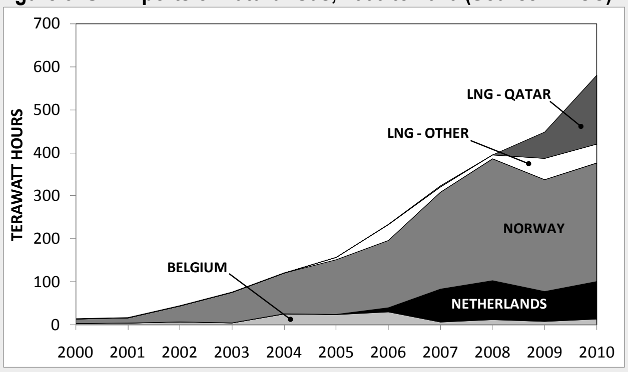
Box 2. Trends in UK Energy Diversity
As shown in Figure 2, below, the diversity of energy resources used in the UK has increased over the last 40 years. Gas and, to a lesser extent, nuclear and renewable energy sources have reduced the dominance of coal and oil. This shift has been reflected particularly in the technologies used to generate electricity.

Figure 2. UK Energy Resource Use, 1970 to 2010 (Source: DECC)



Another area for diversification is the source of the fuels used. As indicated by Figure 3, new infrastructure allows natural gas to be imported via pipeline from Norway, the Netherlands and Belgium, and via ship (as liquefied natural gas; LNG) from Qatar and other countries.

Figure 3. UK Imports of Natural Gas, 2000 to 2010 (Source: DECC)



Although the variety of fuels, sources and technologies has increased overall, it has been reducing in certain sectors. For instance, gas-fired central heating now dominates the residential sector (although this trend may reverse due to decarbonisation policies), while the transport sector relies almost exclusively on oil. The central scenario of the International Energy Agency's *2011 World Energy Outlook* sees the variety of oil sources decrease to 2035.

Electricity Capacity Margin
The electricity market and the role of the system operator, National Grid, were designed to ensure supply matches demand both now and in the future. The majority of supply is arranged through the market, but in the short term – the four hours before plants are actually run – National Grid arranges backup *operating reserves* to manage any unexpected fluctuations in supply and demand. In the longer term – hours to years in advance – the market determines how much capacity is available. The *capacity* or *system margin* describes total future capacity compared with expected peak demand. A *de-rated* capacity margin reflects the amount of capacity expected to be technically available to generate at times of peak demand. This accounts for equipment failures, variability in wind generation and so on.[9]

Fuel Storage Capacity
The UK has varying levels of storage capacity for each of the major fuels used – coal, oil and gas. Coal is relatively easy to store, being a solid fuel. Electricity generators are the main users of coal, and hold stocks for use when it is more competitive than gas. (Note that the industry's ability to switch between coal and gas will be reduced as coal stations are closed to meet EU directives.[2]) Gas and oil storage requires more costly infrastructure. As discussed on Page 4, there is debate over how much additional storage the UK needs and who should provide it.

Demand
Many studies show that reducing and adjusting energy demands can contribute to energy security. Households or businesses with lower and less "peaky" demands are easier to supply and less exposed to energy price increases. Indicators related to consumers and energy demands are thus relevant to energy security. Options include:[4]

- overall energy demand
- energy demand per home or unit of economic activity
- energy costs as a proportion of total expenditure, which indicates the severity of exposure to price increases
- capacity for demand side response (discussed below).

Achieving Energy Security
Balancing Supply with Demand
A fundamental requirement of energy security is to balance supply and demand, both instantaneously and over time. Instantaneous balancing is particularly challenging for electricity because it is difficult to store (POSTnote 372). Around one fifth (19GWe) of the UK's generation capacity is due to close over the next decade. To meet greenhouse gas and renewable energy targets, the government aims to encourage a large amount of new variable renewable generation and relatively inflexible nuclear generation.[9] Flexibility will be needed to maintain a balance between supply and demand. On the supply side, this could be provided by new flexible generation capacity (such as gas-fired power stations), greater interconnection with neighbouring countries, or a greater use of storage. On the demand side, it could be provided by responsive demand that can be reduced (or increased) at times of supply imbalance.[1,2] The respective role for each of these options remains highly uncertain.[1]

With the aim of ensuring that sufficient flexible capacity is delivered by the market, the government plans to introduce a "Capacity Mechanism" as part of a wider electricity market reform.[9] To facilitate the mechanism, the Energy Act 2011 requires the Secretary of State to assess the appropriate level of capacity for the following four years, from late 2012 onwards. The electricity and gas market regulator, OFGEM, will support this by estimating future capacity margins and the associated risks of supply shortfalls. Estimating the relationship between these two is not new; it underpinned the central planning of the pre-privatised electricity system.[10] However, the assumptions and methods require refinement for the greater uncertainties of a market-based system with increasing amounts of variable renewable generation, storage, interconnection, and responsive demand. OFGEM has consulted on a workable method and will publish its conclusions in early 2012.

In both the gas and electricity markets, some capacity for responsive demand already exists through interruptible contracts with industrial and commercial businesses. However, a recent study on gas security flags a reduction in interruptible gas contracts.[11] Reversing this position is one of the options being considered in OFGEM's current gas security review. In the future, smart meters could bring households and smaller businesses into the market for responsive electricity and gas demand, though this depends on consumer willingness to participate (POSTnote 372).

Oil and Gas Storage Capacity

Because oil and, to an increasing extent, gas are traded in global markets, the UK's energy security depends on international (as well as national) energy policy. This includes participation in the International Energy Agency, which co-ordinates emergency oil stocks and oil crisis planning for OECD countries. With UK oil production in decline, the UK Petroleum Industry Association estimates that £4-5 billion of extra storage will be needed by around the end of the decade for the UK to meet its international obligations. There is debate over whether further storage should be developed by private industry or an independent stockholding agency.[1]

On gas storage, the UK has little capacity by European standards – equivalent to 14 days' worth of supply compared with between 59 and 87 days in Italy, Germany and France. This is partly because UK storage was seen as unnecessary when substantial gas reserves existed in the North Sea. With those reserves now in decline, debate has intensified over the need for more storage capacity, and whether government intervention is required to ensure sufficient development. In light of the evidence it received, the ECC Committee has called on the government to develop a storage strategy to increase capacity significantly.[1]

DECC emphasises that storage is but one part of a flexible market for gas, which includes having diversity in suppliers and import routes. Recent analysis[4,11,12] suggests that the UK currently has a resilient gas system, but DECC sees challenges in the medium to long term. The Energy Act 2011 has therefore given OFGEM the power to reform gas balancing arrangements, which it should decide upon by late spring 2012.

Informing Policy Decisions

The government's stated aims for energy policy are to reduce greenhouse gas emissions while providing secure and affordable energy to consumers. A balance must sometimes be struck between these differing objectives. For example, diversity and redundancy in infrastructure improve energy security but compromise affordability. Economic cost-benefit analysis (CBA) is often used in an attempt to quantify such trade-offs and aid policy decisions. DECC is, for example, using CBA to inform its programme of electricity market reform.[9] However, there are difficulties with CBA, including that:

- the benefits of energy security are difficult to quantify
- public perception of the benefits may differ from the economic evaluation
- the method can assess only risks whose probability and potential impact can be modelled with confidence.

Given the uncertainty and even ignorance associated with some threats to energy security,[5] the last point implies that other approaches are needed to complement CBA.[4] One alternative is "stress testing". This can take the form of practical exercises, such as the government's 2011 "Exercise Watermark", which tested Britain's emergency response system for future floods. It can also be used in conjunction with scenario analysis. Scenarios of plausible future energy systems can be built and tested to investigate their resilience to possible disruptions, such as how the gas system would cope with a major disruption at a gas terminal, whether the electricity system could cope with less gas for generation, or how security investments, such as in gas storage, would increase resilience to those shocks. Various studies have done such testing to assess how energy policies could affect the UK's future energy security.[4,11,13]

The advantage of stress testing is that it does not require knowledge about the cause and probability of a disruption. However, this very fact makes it difficult to identify the greatest risks and thus decide where to focus energy security policy and investment. In one attempt to address this, researchers treated security investments as insurance against disruptions.[4] If the cost of an investment is lower than that of a disruption, it could be justified if the disruption is feasible within the lifetime of the investment.

Energy security is achieved by the energy system operating successfully as a whole, and its continuity is subject to numerous uncertainties. This does not mean that aspects of energy security cannot be usefully measured, but rather emphasises that any set of indicators is partial. A broad, inter-disciplinary approach involving a range of interested groups is thus advantageous when informing energy policy.

Endnotes

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