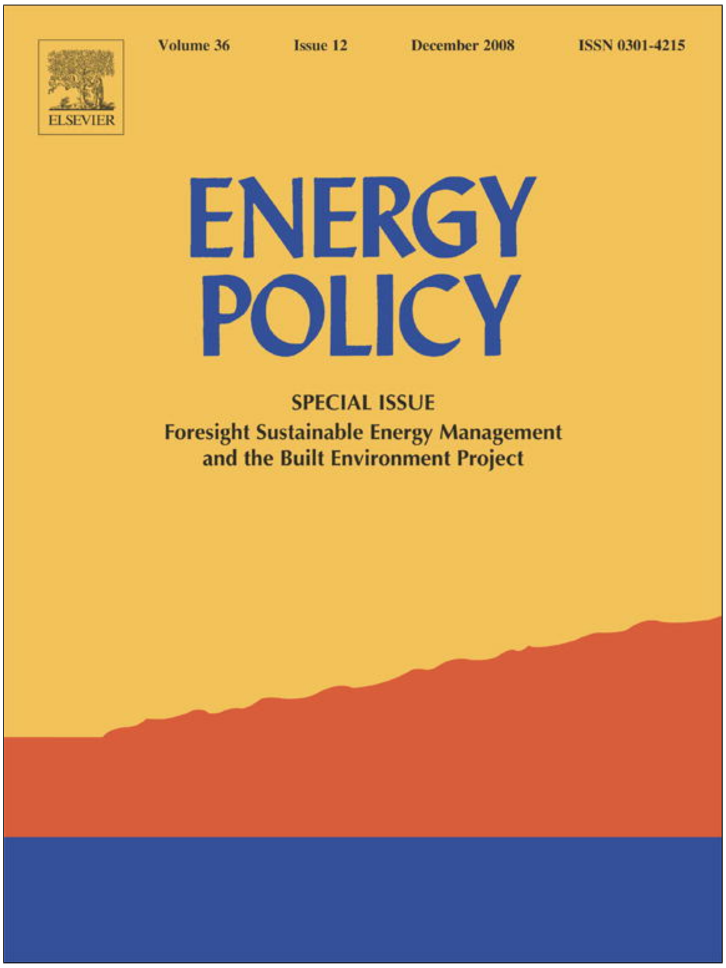
Volume 36
Issue 12
December 2008
ISSN 0301-4215
ELSEVIER
ENERGY POLICY
SPECIAL ISSUE
Foresight Sustainable Energy Management
and the Built Environment Project

Energy Policy 36 (2008) 4509–4513

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

The implications of an increasingly decentralised energy system ☆

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ARTICLE INFO

Keywords:
Decentralisation
Microgeneration
Regulation

ABSTRACT

The UK government has signalled that the increasing use of decentralised energy forms part of its plan to achieve the UK's contribution to the EU's sustainable energy targets. Much of the technology for decentralised energy already exists, although it is not widely used in the UK. There will be need for new developments in onsite energy production, and in the delivery, integration and regulatory infrastructure to support it. Other State of Science reviews for this project describe particular energy technologies, but this paper highlights selected developments in thermal technologies and in biological processes which offer the potential for breakthroughs in converting biomass to energy. The effectiveness and deployment of decentralised energy can be enhanced by systems and infrastructure technology, not just for electricity but also in heat and biogas networks. Such systems are expected to be a focus of rapid development over the next two decades. Opportunities exist particularly in active networks, smart metering and intelligent tariff-interactive load management.

Substantial regulatory and policy reform will be required to optimise the potential for onsite energy generation and effective two-way interchanges with centralised energy systems. There will be need for a regulatory system for heat networks and appropriate incentives for active networks. The development of an energy services business model in the industry will not progress until the compensation model changes to make it viable. The strength of the drivers for a trend towards decentralised energy, coupled with a wide range of scientific developments, should make this a very dynamic sector and present a host of new opportunities for British technology.

1. Decentralised energy

Energy security and climate change are now providing strong drivers to a more decentralised energy system which produces power and heat close to the point of use.

It is now accepted that a sustainable energy system needs to adhere to the principles of an energy hierarchy (REA et al., 2006), where the top priority is energy conservation, the next is sustainable production (primarily renewables) and the lowest option is depletive energy generation (fossil and nuclear). In this context, decentralised energy will be favoured over traditional centralised electricity generation, to reduce generation and distribution inefficiencies and to facilitate increased contributions from renewables and combined heat and power (CHP).

The concept of decentralised energy (Greenpeace, 2005) represents a change to the approaches to energy production, supply and networks which have been prevalent in the UK, though there are countries such as Denmark where a decentralised system has been pursued for some decades (Tech-Wise, 2002).

A plethora of terminology is already becoming widespread in this field with frequent references to 'decentralised energy', 'distributed generation', 'micro-generation', 'on-site energy' or 'on-site renewables'. Few have been satisfactorily defined, though there is a statutory definition of micro-generation (Energy Act 2004 Clause 82). For the purpose of this paper, the term 'on-site energy' will be used to mean the production and distribution of energy within the boundaries of, or located nearby and directly connected to, a building, community or development. It may apply to heat, electricity or other energy carriers such as biogas. On-site energy systems may be connected to external energy networks, especially the electricity grid, from which they may both import and export energy.

In addition to its implications for energy conversion, on-site energy offers many new opportunities for novel approaches to energy carriers, networks, delivery mechanisms, user interfaces and the policy and regulatory framework, which this paper now reviews individually.

1.1. On-site energy production and conversion

Several technologies exist for the on-site production of renewable electricity, heat, CHP and fuels. Many of these are mature, though some are not widely used in the UK at present.

☆ While the Government Office for Science commissioned this review, the views are those of the author(s), are independent of Government, and do not constitute Government policy.

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doi:10.1016/j.enpol.2008.09.021

The primary electrical renewable technologies for on-site use are photovoltaics (Boreland and Bagnall, 2008), wind (Tavner, 2008) and hydro. At the scale of most decentralised energy applications (below 1 MW, say) the latter two are usually referred to as micro-wind and micro-hydro.

On-site heat generation from sustainable sources is relatively underdeveloped in the UK compared to many other countries. It may involve various types of bioenergy boiler (Taylor, 2008), solar thermal conversion, ground and air source heat pumps. The state of science of those not covered in other papers in this project is outlined below.

Fuel-burning technologies may also be adapted to produce both electrical power and heat through one of a number of CHP technologies (Hinnells, 2008), which on this scale are referred to as micro-CHP. On-site heat and power may also be obtained by the use of fuel cells (Edwards, 2008).

Finally, renewable bioenergy sources including waste provide the potential for the production of renewable fuels in solid, liquid and gaseous forms. These provide a medium for energy storage and its subsequent conversion to electricity, heat or motive power. Most such fuel production technologies are applied on a large scale, but some—in particular anaerobic digestion, as further described below—are suitable for decentralised applications.

1.1.1. *Solar thermal conversion*

There are two widely used types of solar thermal converter:

- flat-plate designs operate without concentrating the sun's rays and are similar to a dark central heating radiator which absorbs rather than emits heat;
- evacuated tube designs enclose the heat collector pipe in an evacuated glass tube, achieving higher temperatures.

Both approaches are well proven. Though there are manufacturers of both in the UK, the market leaders are overseas. Incremental developments continue to improve efficiencies and reduce costs.

There have been novel developments in the UK of lower-cost flat-plate collectors using plastic rather than metallic collector pipes. Future developments in solar thermal technology are expected to be incremental rather than fundamental.

1.1.2. *Heat pumps*

Heat pumps use electrical energy to pump heat from local sources. The three main types are:

- Ground source heat pumps, which obtain the heat from underground coils or boreholes accessing the fairly steady temperatures available there, typically about 12 °C in the UK.
- Air source heat pumps extract heat from the ambient air. This means more seasonal variation.
- Water source heat pumps use a nearby river or lake as the heat source.

The technology of these devices is relatively mature. Continuing development may raise their coefficient of performance—the ratio of heat out to power in—from present levels in the range 3–4 (Wemhöner and Afjei, 2006). Most research, development and production capability is overseas.

1.1.3. *Anaerobic digestion*

Anaerobic digestion is a process that uses micro-organisms to convert biomass feedstock to bio-methane leaving a residue (or digestate), which can be used as a fertiliser and in other ways. The process can use a wide variety of feedstocks including residues and wastes from agricultural, forestry or industrial processes. The biogas can be burned for heat and/or power production, or be compressed and used as a transport fuel.

There are a number of anaerobic digestion processes, which operate at different temperatures and cycle times. Again the major technology developers are mainly overseas, especially in northern Europe, though there is a base of specialist expertise in the UK.

Developments centre on biochemistry, particularly with a view to accelerating the conversion process. This technology will probably continue to evolve in the longer term.

1.1.4. *Other biomass to gas or biomass to liquid technologies*

The production of biogas and biofuels is an area of rapid development even for relatively established concepts such as gasification and pyrolysis. An evolving technology area is microbial energy conversion, where a number of different approaches have been identified and the research needs of each defined (AAM, 2006).

Most techniques are currently being developed for exploitation at an industrial scale. It may be expected that some will prove themselves capable of scaling down and of being applied within a decentralised energy network. An example is the conversion of food and supermarket wastes to biofuels, which can be used for local power and heat production. Within 20 years this fuel source could power a significant new form of on-site power generation.

1.2. *Energy transport and networks*

On-site energy allows for the possibility of stand-alone power supplies for individual users. But in practice most will be used to provide energy to a number of local users and decentralised systems will usually be connected to national or regional ones. The following types of network may be involved:

- Electricity networks—decentralised systems will normally be connected to a distribution network rather than to the high voltage transmission network.
- Gas networks—primarily that now used for natural gas.
- Heat networks, usually using the medium of hot water or steam.

The existing electricity and gas networks have been designed for a centralised energy system where a small number of power stations and gas sources feed outwards through a branching network to a large number of individual users.

A trend towards on-site energy will place new requirements on these networks.

1.2.1. *Electricity networks*

Increased use of decentralised energy will mean that the size and even direction of the power flows in networks will be less predictable than in the centralised model. This creates the need for more active network management, flexible voltage control and sophisticated fault detection and safety procedures.

Government and the regulator have been facilitating these developments, for example by the establishment of the Distribution Working Group of the Electricity Networks Steering Group. The Registered Power Zone concept (Ofgem, 2005) provides a framework within which novel approaches can be researched.

The trend is likely to lead to a need for distribution network operators (DNOs) to become more involved in the management of power flows in their system, an activity traditionally controlled exclusively at the transmission level by the transmission system operator. There is still substantial scope for the development of methodologies and equipment to optimise energy flows under this regime (McDonald, 2008).

Longer-term developments are likely to lead to increased integration within networks of the load management and user interfaces. This is discussed below, as are options for the distribution system within buildings.

1.2.2. *Heat networks*

The technology for local distribution of heat is also developed and widely used overseas, though not extensively in the UK.

The main developments in this sector, therefore, are not expected to be technological, but regulatory (as discussed further below) and behavioural.

1.2.3. *Gas networks*

The local production of biogas through anaerobic digestion and similar technologies provides the opportunity to interact with the gas grid in the same way as on-site power will with the electricity network.

This approach has been adopted in Germany (BMU, 2007) and should be applicable in the UK. There will be a need to develop the necessary expertise, inter alia in quality specification, pressure control, metering and safety. Once this has been achieved no substantial long-term developments are anticipated.

1.2.4. *Solid and liquid fuel transport and processing*

Renewable fuels in solid and liquid form may be transported by traditional means from where they are produced to where they are used, or to fuel carriers for intermediate processing before use. Further technological development is probably needed and may justify separate assessment.

1.3. *Energy storage*

An increasingly decentralised energy system could offer substantial opportunities for storage, especially as few renewable energy generation sources are ‘on demand’ and many are intermittent. Load management is a form of ‘virtual storage’ as it can delay the timing of energy consumption in the same way that traditional storage delays the time of energy delivery.

Any electricity, gas or heat grid to which the user is connected may be considered as storage if it can accept surplus energy when available and deliver energy shortfalls as required. There are also several on-site energy storage options.

1.3.1. *Heat and coolth storage*

The most obvious heat storage is the hot water cylinder or heat store used in most premises. These typically provide storage over periods of hours to days. The technology of such systems has developed so they now achieve high levels of energy efficiency and can interact with a variety of input sources. Continued incremental development may be expected but radical change seems unlikely.

More extensive heat storage, for example providing season-to-season storage, is not widely used, though some demonstration systems have been applied. These typically use much larger thermal reservoirs with either phase change materials or underground aquifers. This may be an area for longer-term research to achieve effective seasonal storage at an acceptable price. It seems unlikely that there will be substantial progress here within the next 20 years.

Clearly coolth can also be stored. Fridges and freezers may be considered to be such stores.

1.3.2. *Electricity storage*

Electricity storage in decentralised systems currently depends mainly on traditional batteries. These are used in a wide variety of small consumer products and for uninterruptible power supplies, but do not represent a significant proportion of electricity usage. It may be that improved battery technology could lead to more decentralised electricity systems incorporating a standby battery to increase energy security, particularly if the centralised electricity grid becomes less reliable through interruptions to fuel supplies or ageing infrastructure. The main drivers to battery development will probably be in other markets such as transport. On-site energy systems may take advantage of such advances as they become available, rather than leading the research efforts.

Other energy storage systems, such as flywheels (NASA, 2004), have been developed and applied in selected applications. While research will doubtless continue, decentralised energy is unlikely to be a major driver for the science.

1.3.3. *Fuel storage*

Where the on-site energy conversion process uses a renewable or fossil fuel, this fuel can clearly be stored for use when it is needed. For liquid or gaseous fuels this is likely to involve traditional technology such as oil tanks or pressurised containers.

Solid fuels may need more customised storage facilities, especially where the storage conditions need to be controlled, for example to ensure that wood pellets or chips do not become too damp. There is likely to be continuing development of such devices and of automated delivery mechanisms to make solid fuels easier for consumers to use.

1.4. *User interfaces*

1.4.1. *Consumer energy distribution*

Traditional energy distribution within premises takes its characteristics from the mains network to which it is connected. Electricity, for example, is distributed in the UK at 50 Hz AC, but much domestic electricity consumption takes place in low-voltage DC appliances. This means that many devices incorporate AC to DC rectification, which is often inefficient and is a substantial contributor to parasitic losses.

There may be a case for incorporating an additional DC distribution network within buildings or even for using only DC. But most buildings are not currently wired for this option. While new buildings could use this approach, it would take a long time to roll out universally. This development might be progressively adopted over the next half-century or so.

1.4.2. *Monitoring and metering*

The increased use of decentralised energy is likely to lead to substantial and welcome developments to the availability of information about energy flows in the system.

Most on-site energy systems incorporate displays showing the level of energy production, and often provide information on consumption. This has had a positive effect on users' knowledge of their energy regime and often leads to improved conservation.

This trend is entirely complementary with a ‘smart metering’ approach, and is likely to become essential as the number of systems both importing and exporting energy increases. This development would also benefit the energy supply companies, as it would enable them to automate meter-reading procedures and manage loads more effectively.

The science of metering and monitoring is expected to advance substantially over the next two decades. Increasingly sophisticated devices will be configured to operate flexibly with a range of external and on-site utilities, perhaps including water as well as energy. Remote communications devices are likely to be important.

1.4.3. Load control

Although load control is not strictly a decentralised energy issue, the use of more intelligent load control is highly complementary to decentralised energy supply. For many appliances, such as dishwashers, washing machines, fridges and freezers, the time they run is not critical within limits. They can be switched on as the availability or price (Zhang and Feliachi, 2003) of energy dictates.

There is great potential for simple devices to activate these appliances at the appropriate time. These devices could be incorporated into the appliance, the electricity socket, or the consumer unit. They could be activated by sensing the electricity supply, or signals multiplexed onto it, or by remote telecommunications. The latter option is considered most appropriate as it would also facilitate the control of non-electrical loads such as heating.

There is very substantial potential to develop science in this area over the next several decades.

1.4.4. Energy management

There is immense potential for integrating intelligent energy management and metering. This would combine the use of energy at the most appropriate time with billing mechanisms to reward such behaviour.

Again, substantial scientific and regulatory development should be anticipated in the coming decades.

1.5. Policy and regulation

In practice, policy and regulation will influence the deployment of decentralised energy at least as much as technological factors. The regulatory science therefore also needs evaluation.

1.5.1. Policy considerations

Although the UK now has a ‘Microgeneration Strategy’ (DBERR, 2006), tangible energy policy measures and incentives have been directed almost exclusively towards centralised electricity generation. An increasing contribution from decentralised energy is now included in government policy (DBERR, 2007), but requires several policy and regulatory obstacles to be overcome.

The technical requirements for connecting on-site energy systems to the grid networks are progressively being eased at the low power end, with the transition towards a ‘connect and notify’ approach in the Distribution Connection and Use of System Code and the revision to Engineering Recommendation G83/1. There is still need for further developments in this area and particularly at the intermediate scale, to facilitate a growing number of installations without placing an undue burden on distribution network operators.

The planning requirements have yet to be adequately clarified, though it is intended that many on-site energy systems will in due course be covered by a Permitted Development Order (DCLG, 2006).

1.5.2. Development incentives

Current policies provide fewer incentives for decentralised systems than for centralised renewables under the Renewables Obligation. Though small systems are technically eligible, the transaction costs are high and the administrative arrangements cumbersome.

The Low Carbon Buildings Programme provides limited support for on-site installations but is due to end in 2009. On-site energy installations are scheduled to become eligible under the Carbon Emissions Reduction Target at about that time, but this is expected to support only a limited number of installations.

A more comprehensive incentive mechanism is likely to be required to meet the new EU energy targets. This will need to be complementary to support mechanisms for centralised systems. Some proposals on such an approach have already been advanced (Wolfe, 2007) and at the time of publication are being considered as part of an evolving Renewable Energy Strategy (DBERR, 2008).

1.5.3. Regulatory structure

An increase in on-site energy will require changes to the way in which the energy sector is regulated, and its prices controlled, by the regulator. The development of active distribution networks described above will also require changes to the distribution pricing approaches adopted by Ofgem (SDC, 2007). It may also be necessary to extend regulation to new areas such as heat networks.

In general, a move towards decentralised energy will support a transition of the role of energy companies from being supply-focused to being service-focused. Most major incumbents are interested in developing the concept of energy service companies, but an entirely new regulatory and pricing mechanism will be needed to enable this transition.

2. General outlook for decentralised energy

The recently adopted EU sustainable energy targets should help Europe to establish world leadership in several of these fields.

Though the UK lags in renewable energy deployment, our expertise in related areas provides substantial opportunities in key emerging sectors.

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