# P02a Working Paper Three

## The Economic Value of Micro Generation

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The Economic Value of Micro Generation

Summary

The DTI and Ofgem initiated work on micro generation. Part of this work involves a consideration of metering & settlement. Project P02a was set up to undertake this activity. One area considered by P02a was the economic value of micro generation.


**Uniqueness of micro generation** - Electricity supply from micro generation is a mass-market method of producing electricity with a product rather than a “bespoke” power project. Micro generation is energy efficient, well matched to demand and is environmentally friendly. Moreover micro generator electricity is produced and consumed on the premise, or very close electrically and geographically to the premise, where it is produced. These factors make micro generation unique.

**Value of electricity from micro generation** – Ignoring taxes, profits and Licensed Electricity Supplier (LES) other supply costs the economic cost of a kWh of electricity at the point of connection to the low voltage network is the cost of producing the kWh of electricity; plus the cost of delivering the kWh of electricity including losses; plus the cost of the environmental damage to produce & deliver the kWh of electricity. This cost is also a function of time. There are two particular corollaries of this proposition; firstly the value of the kWh is the avoided cost; and second the value of the kWh does not depend on which side of the customer’s terminals it is measured at, on the premise.

**Barriers to micro generation market entry** – Even in countries such as the UK there are still significant barriers to micro generation. Institutional arrangements were never designed to enable the connection and settlement of micro generation or facilitate competition in energy “off-take” and “supply”. The New Electricity Trading Arrangement (NETA) and “Competition in supply” were not designed with micro generation in mind. Moreover there are subsidies that have grown up over many decades with the centralised model of electricity production and transmission & distribution (T&D) in mind.

** Provision of generating capacity from micro generation** – Capacity from micro generation can easily be added to the power system because it can be installed quickly and it matches the scale of demand. Furthermore it is modular, has little financial risk and has zero or very-low environmental footprint. Finally, capacity from micro generation is automatically well diversified in terms of kW size and geographic location.

** Provision of network capacity kW from micro generation** - If micro generation coincides with peaks it reduces the total capacity needed within networks because it reduces the amount of electricity delivered across T&D systems. Less than 10% of the cost of distribution capacity is associated with the provision of network capacity below the 11 kV system (“The Structure of Electricity Distribution Charges - Initial Consultation Paper” December 2000, Ofgem). As one moves through the power system from high voltage to low voltage (LV) the load factor of assets decreases significantly. Adding micro generation to the LV network will defer or remove altogether the need for new
network capacity. The SIAM study (System Integration of Additional Micro-generation, September 2004, DTI contract DG/CG/00028/REP) concluded that the economic cost of accepting more than 17GW of micro generation into the British network is comparatively small and substantially less than the wider benefits that such a level of micro generation would bring.

**Potential speed of installation of micro generation** – This represents a sea change in thinking as to whether or not in the short term both generating and network capacity is fixed. For example every year in the UK about a million gas-fired boilers are installed. If half of these boilers were micro combined heat & power (mCHP) with 1.5 kW_e capacity then 750 MW of capacity would be installed or around 15 MW per week.

**Provision of energy from micro generation** – The major cost of providing kWh from any prime mover is related to the cost of fuel. Micro generators have zero or very low fuel costs because they either run on renewable energy, or they run as mCHP.

**Energy efficiency and micro generation** – Micro generation utilises primary resources far more efficiently and effectively than large-scale power stations, transmission and distribution systems. A micro generator of only a few kW is an extremely efficient way to utilise primary energy.

**Consumption of electricity produced by micro generation** - “On The Premises” consumption of micro generator electricity reduces power system costs - production, delivery, environmental damage and losses. “Off The Premises” consumption also reduces power system costs. In “Off The Premises” consumption the nearest electrical load to consume the electricity - electrically and geographically - is a close neighbour primarily the premise next door. In this consumption there is a reduction in power system costs together with a potential marginal increase in operating costs for the network operator associated with usage of the cable or overhead line in the street between premises. Clearly it is not correct to charge full delivery costs for electricity that is produced next door and delivered “over the fence” as this represents cross subsidy. As micro generation reduces the overall cost of transmission and distribution this benefit could be passed to the micro generator owner or shared between all customers i.e. no special provision for micro generation.

**Micro generation and the environment** – Renewable energy micro generators are “Carbon free” electricity producers and if the displaced energy is from a fossil fuel plant it will reduce total Carbon Dioxide (CO_2) emissions. Micro generators that produce electricity from fossil fuels, ignoring bio fuels, and operate in CHP mode are “Carbon abatement” electricity producers. There is little, if any, environmental impact from micro generation in terms of visual intrusion and emissions to land, air and water and micro generation has no long-term environmental implications e.g. storage, contamination, interference, visual intrusion, decommissioning etc.

**Electricity Costs Table E1** - We compared the cost of electricity supply from new micro generators with the cost of electricity supply from new base-load large-scale central power stations. We included delivery in this comparison together with some environmental costs based on trading CO_2. Our comparison should be treated carefully because we compared emergent technologies with learned out technologies. Our micro generator data are no more than an indicative view and with the possible exception of
micro wind/hydro, cost data in particular are expected to change through procurement, automation, design and technology change.

Table E1 - Total costs of providing a kWh to a low voltage network customer

<table>
<thead>
<tr>
<th>Prime Mover</th>
<th>Total Costs P/kWh</th>
<th>Variable Costs p/kWh</th>
<th>Energy Utilisation %</th>
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<tbody>
<tr>
<td>Micro CHP\textsuperscript{1} Internal Combustion Engine three phase</td>
<td>5.57</td>
<td>1.99*</td>
<td>80</td>
</tr>
<tr>
<td>Micro CHP Internal Combustion Engine three phase NSD\textsuperscript{2}</td>
<td>3.7</td>
<td>1.68*</td>
<td>85</td>
</tr>
<tr>
<td>Micro CHP Internal Combustion Engine single phase</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Micro CHP Stirling External Combustion Engine single phase</td>
<td>4.76</td>
<td>2.28</td>
<td>80</td>
</tr>
<tr>
<td>Micro CHP Rankine External Combustion Engine single phase</td>
<td>4.5</td>
<td>2.46</td>
<td>80</td>
</tr>
<tr>
<td>Micro CHP Proton Exchange Membrane Fuel Cell single phase</td>
<td>20.46</td>
<td>1.82</td>
<td>80</td>
</tr>
<tr>
<td>Micro CHP Solid Oxide Fuel Cell single phase</td>
<td>28.23</td>
<td>1.86</td>
<td>80</td>
</tr>
<tr>
<td>Micro Proton Exchange Membrane Fuel Cell single phase</td>
<td>12.07</td>
<td>3.38</td>
<td>40</td>
</tr>
<tr>
<td>Micro Solid Oxide Fuel Cell single phase</td>
<td>16.16</td>
<td>3.86</td>
<td>35</td>
</tr>
<tr>
<td>Micro hydro single phase</td>
<td>2.7</td>
<td>0.0</td>
<td>67</td>
</tr>
<tr>
<td>Micro photo voltaic single phase</td>
<td>33.75</td>
<td>0.0</td>
<td>12</td>
</tr>
<tr>
<td>Micro wind single phase</td>
<td>4.63</td>
<td>0.0</td>
<td>40</td>
</tr>
<tr>
<td>Combined Cycle Gas Turbine (CCGT)</td>
<td>4.35</td>
<td>1.38</td>
<td>48</td>
</tr>
<tr>
<td>Flue Gas Desulphurised (FGD) Coal</td>
<td>4.65</td>
<td>0.84</td>
<td>30</td>
</tr>
<tr>
<td>Nuclear</td>
<td>3.57</td>
<td>0.31</td>
<td>29</td>
</tr>
<tr>
<td>Waste</td>
<td>4.8</td>
<td>0.0</td>
<td>26</td>
</tr>
</tbody>
</table>

Notes to Table E1:
- **Total costs** - Equal to the sum of production costs, delivery costs and CO\textsubscript{2} costs. Production costs consist of capital remunerated at 5\% and fuel costs. Delivery costs are average use of system charges – Ofgem Structure of Charges document December 2000. CO\textsubscript{2} cost at £12/tonne & Carbon burdens from defra web site.
- **Variable costs** - Equal to fuel costs: running and fixed other works costs are excluded.
- **Energy Utilisation** – % of the input energy that is usefully used by the end user. T&D Loss assumed at 7\%.
- \textsuperscript{1} CHP - Combined Heat and Power  \textsuperscript{2} NSD - New Supplier/Developer
- All costs exclude taxes, any profits, Licensed Electricity Supplier other supply costs, metering costs and maintenance costs.
- All ICE capital costs allocated to electricity production. In practice a proportion of these costs will be offset by avoided boiler capacity costs.
- \textsuperscript{3} ICE Electricity costs calculated on a marginal basis. Only valid if ICE replaces boiler or is a very small part of the thermal capacity when working alongside an existing boiler.
- Fuel costs - CCGT gas 20 p/Therm (0.76 p/kWh), domestic gas 1.35 p/kWh, coal £30/tonne including delivery, ICE gas 1.05 p/kWh - based on contract gas prices and Nuclear fuel costs 0.05 p/kWh excluding long-term liabilities & back end costs.
- Costs of CHP units based on supply volumes greater than 100,000 units per year.
- Fuel Cell prime movers are based on a 3kWe PEM or SOFC cell and are assumed to emit no CO\textsubscript{2} as they are supplied by green Hydrogen. Supply volumes ca. 100,000 per annum.
- No account of the time of day benefits attributable to micro generators.

**Conclusions** – Our principal conclusions are:

- Micro generation delivers a range of economic benefits to the UK economy over and above low cost energy, in particular:
  - It will reduce emissions of CO\textsubscript{x}, SO\textsubscript{x}, NO\textsubscript{x} and particulates.
It will reduce the total capacity needed within networks.
- It will reduce the need for peak provision in electricity networks.
- It will reduce power system losses.
- It will deliver major energy efficiency gains.
- It will automatically provide diversity in terms of power and location.
- It will reduce the amount of large-scale centralised generating capacity.

Mechanisms to access all these benefits either do not exist or at best can be described as emergent and/or restrictive.

- The majority of micro generation is competitive with other forms of electricity supply; however, the current institutional arrangements for electricity trading do not reward micro generation equitably. The embryonic mechanisms for trading micro generation output only potentially reward energy and rely on the development of a “competitive market”. Current arrangements encourage micro generation development to displace kWh supplied to premises. This is an odd incentive and needs correcting as it will lead to sub optimal economic solutions.

- Current institutional arrangements mean that only LES can take micro generator output - see P02a working paper two. Competition issues exist with this arrangement as the same LES could be purchasing and selling at the same time from the same premise. Although it must be pointed out that customers could contract with different LES for import and export. Furthermore LES could potentially influence the installation/non-installation of micro generation for their own commercial benefit.

- It is clear that when micro generated units of electricity are exported onto the LV network there are market failings in terms of cost allocation. These market failings need correction to allow a rational outcome that more accurately reflects the economic value of electricity generated by micro generation.

- It is wrong to charge full delivery costs for micro generator’s electricity that is exported next door. If a competitive “off take” market does not emerge it will be equally wrong to allow electricity “off-takers” (LES in E&W) to take benefit (arbitrage) for electricity they have obtained at the bottom of the power system (LV network).

- The introduction of micro generation heralds a sea change in thinking regarding both generating and network capacity being fixed in the short term.
I INTRODUCTION

1.1 Over the past decade the electricity industry in the UK has changed considerably in the areas of ownership, institutional arrangements and choice of supplier. Generally speaking power systems are slow to respond to change and sudden change carries the risk of creating stranded assets. That said the business model for electricity production and delivery has not really changed. We still centrally produce large amounts of electricity and transmit it over long distances.

1.2 The trend of bigger plants and falling costs has actually reversed; medium size gas plant, combined heat and power and wind turbines are portents of a new electricity production business model based on distributed or embedded generation. Micro generation represents the final shift from medium-scale distributed technologies to small-scale distributed technologies.

1.3 As an operational definition of micro generator we use the industry’s Engineering Recommendations. In particular the capacity constraints contained in Engineering Recommendation G83/1 published in September 2003 - Recommendations for the connection of small scale embedded generators (up to 16 Ampere per phase) in parallel with public low-voltage distribution networks. For clarity 16 Ampere per phase equates to 11.04 kVA for a 400 Volt three-phase connection, or, 3.68 kVA for a 230 Volt single-phase connection.

1.4 Micro generation is unique. Principally, unlike all other forms of electricity production, micro generation of only a few kW of electrical capacity is:

(a) An extremely efficient way to utilise primary energy;

(b) A mass market method of electricity production;

(c) Well matched to the scale of demand it supplies;

(d) Environmentally friendly - Carbon neutral or Carbon reducing; and

(e) A product rather than a “bespoke” power project.

Moreover, electricity from micro generation is both produced and consumed on the premises, or very close to the premises, where it is produced. Close here means both electrically and geographically close, i.e. next door but two, in the case of a domestic premise and next door in the case of a larger premise.

1.5 There are a number of micro generation technologies. The primary technologies or families of technologies are Micro Wind, Micro Hydro, Fuel Cells, Photovoltaics, Internal Combustion Engines (ICEs), External Combustion Engines (ECEs) and micro combined heat and power (micro CHP) with a variety of prime movers, principally ICEs, ECEs and Fuel Cells. Micro generator technologies with electrical production capacities as low as 1 kW are now entering the market for power. To put this in perspective 1 kW represents one-millionth the amount of capacity installed at Rugeley B, a 1,000 MW coal fired power station in the midlands.
1.6 This paper concentrates on the “economic value” or “economic-worth” for micro generation. We address the issue in terms of micro generation’s overall value to “UK plc” without exploring who benefits from that value.

1.7 Including this introduction the paper consists of six sections as set out below.

Section II This section sets out the background to micro generation, discusses some of the barriers to market entry and considers who might install micro generation.

Section III In this section we examine the power system and look where micro generation fits in the system with its associated costs and benefits to the power system.

Section IV The environmental aspects of micro generation are tackled in this section. In particular we compare the environmental costs of producing, transmitting and distributing a kWh from a micro generator as opposed to a large centralised power station.

Section V In this section we summarise our economic analysis of micro generation.

Section VI This section contains the conclusions of our analysis.
II MICRO GENERATION

2.1 Micro generation’s competitive advantage primarily stems from mass production combined with very effective/efficient utilisation of primary resources. We have not seen the impact of mass production yet because to-date micro generators have not entered the market in volume. There is no doubt that micro generators utilise primary resources far more efficiently and effectively than large-scale power stations, transmission & distribution systems.

2.2 Capacity is the primary cost driver for power systems. Micro generators profoundly affect the need for capacity on a power system. Micro generators reduce the need for both power station capacity and transmission & distribution capacity, on the power system primarily because they reduce the amount of electricity produced centrally and transported over transmission and distribution networks at peak times. One of the principal corollaries of this fact is a reduction in losses on the power system. Customers with micro generation will require the same service capacity and power stations, transmission and distributions systems will still need to be sized to meet demands unless maximum demands are reliably reduced.

2.3 There are significant barriers to market entry for micro generation. These barriers have been created over many decades with the central large-scale power system model in mind. Even in countries such as the UK, where electricity markets have undergone unprecedented change there are still subsidies and support, hidden or not, for the owners and operators of large-scale power plant and equipment and large scale energy suppliers, for example virtually guaranteed returns on assets for transmission and distribution operators and support for the nuclear generating industry.

2.4 There are also regulatory barriers to overcome, because regulation of the power market was never designed for micro generation, e.g. connection arrangements, metering arrangements, competition in micro generation electricity production and supply, trading or lack thereof in micro generation output etc.

2.5 Some of the cost barriers to micro generation are formidable, e.g. in the UK these include the costs associated with balancing, settlement, master registration, metering and the cost of becoming a Licensed Energy Supplier (LES). Micro generators don’t have to become energy suppliers, however, the current institutional arrangements mean that only LESs can take any output from micro generators. There will be significant competition issues associated with these arrangements because LESs are purchasing and selling at the same time from the same premise. Furthermore LESs could potentially influence the installation/non-installation of micro generation for their commercial benefit. However, it must be pointed out that the customer could contract with two different LESs one for import and one for export.

2.6 Most large-scale electricity businesses do not perceive micro generation as a serious player in terms of the business of electricity supply. Operators of electricity transmission and distribution systems perceive micro generation as potentially unwelcome because their systems were designed with the large-scale
model of electricity production in mind. Generally speaking operators of transmission and distribution plant find it difficult to respond quickly and the potentially disruptive changes brought about by micro generation will amplify this issue. This problem is particularly acute with distribution network operators (DNOs).

2.7 An energy life cycle analysis for micro generation is beyond the scope of this paper and outside the remit of project P02a. Likewise, a Carbon analysis for micro generation is also out-of-scope within this paper. In any case the externalities of energy life cycle and Carbon analysis are not normally considered in the economics of power generation. Hence, we only examine the economics from the perspective of the decision to install and operate micro generation.

2.8 Individual potential owners of micro generation capacity will take decisions on whether or not to install a micro generator based on a combination of factors e.g. Access to and availability of capital, The need for central heating, for example purchasing a new gas boiler, lifestyle & aspirations, perceptions of “green” and “environmentally” friendly technologies, Control of ones own means of electricity generation, reducing energy costs and energy efficiency considerations. It is clear from these points that decisions will not be made based on the type of analysis undertaken by a power system economist. The decision to install micro generation may also be taken by new build developers and/or Councils. Again this decision making process will probably not involve the type of analysis undertaken by a power system economist.

2.9 As with all power systems once a decision has been made to install a micro generator the costs are sunk. Therefore from a power system operation perspective the only relevant costs for decision-making will be variable costs.

2.10 In pure economic terms the “worth” or “value” of a micro generator kWh of electricity at the point of connection to the low voltage network is:

- The avoided cost of a kWh of electricity production; plus
- The avoided cost of delivering the kWh of electricity including avoided losses; plus
- The avoided cost of environmental damage to produce & deliver the kWh of electricity.

2.11 For the purposes of our analysis we divide the economics of micro generation into two broad categories:

(a) The economics associated with electricity production from micro generation. This can be further sub divided into the economics of providing electrical capacity and the economics of producing electrical energy.

(b) The economics associated with an environmental analysis of micro generation through its installation and usage.

2.12 We now examine both of these categories in some detail and then conclude with a micro economic analysis.
III THE POWER SYSTEM AND MICRO GENERATION

3.1 In an efficient market the supply of electrical capacity and electrical energy in both the short and the long run would be from the lowest cost provider. Electricity markets tend to suffer from problems due to the nature of the business for example the business consists of long-lived capital-intensive assets, companies can suffer from stranded assets, electricity businesses involve significant sunk costs etc.

Capacity - kW

3.2 The economist’s view of power systems is that in the short term capacity is fixed. Micro generation capacity can be added to the power system very easily, because unlike central power station capacity or transmission & distribution capacity micro generation:

(a) Is inherently modular;
(b) Can be adjusted to match the scale of demand;
(c) Can be installed far more quickly than a central station or transmission and distribution line;
(d) Represents much less financial risk than a central station or transmission and distribution line;
(e) Has zero or very low environmental footprint or impact;
(f) Has little or no permitting requirements; and
(g) Can be installed where the power is actually needed.

3.3 The potential speed of installation of micro generation represents a sea change in thinking as to whether or not in the short term both generating and network capacity is fixed. For example in the UK around one million gas-fired boilers are installed per annum. If half of these boilers were micro CHP devices with an average capacity of 1.5 kW then 750 MW of electrical capacity would be installed per annum or around 15 MW per week.

3.4 Micro generation will provide new electrical capacity to the power system. The provision of kilowatts of electrical capacity can be divided into two principal components:

(a) Generating capacity – Essentially this is the provision of power stations to produce energy. It is sometimes referred to as “prime mover capacity”; and

(b) Network capacity – Essentially this is the provision of transmission and distribution facilities to deliver energy. It is sometimes referred to as “infrastructure capacity”.
3.5 Using least cost generation expansion planning techniques it is a straightforward proposition to work out the incremental cost of adding rotating capacity to a power system. In this type of analysis new rotating capacity would operate at very high utilisation or “load factor” in its early life, declining to low load factor at the end of its life. In E&W new generating capacity is not added to the power system on the basis of least cost generation expansion planning. It is added on the basis of a contract for the capacity and energy; or on the basis of a “Merchant Plant” with output to be sold in the electricity market.

3.6 In context 10,000 customers, a very small number of customers, each with a 3kWe micro generator are equivalent to 30 MWe. This is equivalent to a 30 MWe open cycle gas turbine or three 10 MWe diesel engines, or a 30 MW steam turbine. However, the capacity is at the bottom of the network and is completely diversified in terms of unit size and geography. There are additional benefits including reduction in losses, voltage control and capacity reinforcement.

3.7 Economists consider electricity networks as a public good natural monopoly to be regulated and price controlled. In the UK regulatory incentives encourage DNOs to act conservatively and provide spare capacity to avoid customer minutes off supply. DNO network provision for low voltage customers is largely remunerated on the basis of kWh of electricity delivered, as a proxy for maximum demand, which is the true driver for capacity. Asset utilisation decreases significantly moving down the power system from the high voltage to the low voltage end. Network operators have to provide capacity for maximum demands which occur, if at all, infrequently.

3.8 The transmission company and distribution companies in E&W have planning standards that allow the investigation of increments and decrements of 500 MW of capacity. This provides the typical costs of adding 500 MW of network capacity.

3.9 Adding micro generation capacity at the low voltage end of the power system will defer or remove altogether the need for new network capacity and reduce the utilisation of existing network capacity. If micro generation coincides with peaks it reduces the total capacity needed within networks, because they reduce the amount of electricity transported across transmission and distribution systems. Therefore micro generation will profoundly impact network capacity, demands, planning, and operation and hence costs. This has significant implications for network operators.

3.10 Well over 90% of the cost of distribution capacity is associated with the provision of network capacity at and above the 11 kV system including the 11kV to LV
transformation – “The Structure of Electricity Distribution Charges - Initial Consultation Paper” December 2000. Ofgem. Put another way this means that less than 10% of the cost of distribution capacity is associated with the provision of network capacity below the 11 kV systems. This capacity has very low utilisation – load factor – and is planned on the basis of after diversity maximum demand.

3.11 Delivery of a kWh over the power system versus delivery of a kWh “next door” from a micro generator is shown diagrammatically in Figure 3.1 below.

**Figure 3.1 – Delivery of kWh**

3.12 It is clear from this simple diagram that far fewer assets are involved in providing kWh from a micro generator. A fuller treatment of this subject is presented in Appendix D.

**Energy - kWh**

3.13 The cost of providing energy kWh is predominantly related to the cost of fuel purchased to supply power stations. In an efficient market the lowest cost kWh
would be produced first – Baseload - with increasing production costs occurring as demand for kWh increased – Peakload.

Energy - kWh - from Micro Generation

3.14 The majority of micro generators have zero or low fuel costs because they are either run on renewable sources, or run in conjunction with heating loads. In economic terms the worth of the energy is the avoided cost of production of the kWh from a centralised power station plus losses etc.

Losses - kWh

3.15 Delivering energy over the transmission and distribution system incurs losses. These losses need to be included in the overall analysis of the cost of providing energy kWh. In the UK losses run at around two percent for the high voltage transmission system and around six or seven percent for distribution systems. There are regional variations in distribution losses because of such things as: urban, rural, operation etc.

Diversity

3.16 Micro generators provide diversity both in terms of power, kW and location geography. They deliver a completely dispersed supply to the power system. Thereby they increase the security of supply in the network, and theoretically could enable islands of power supply unconnected to the main power system. As set out in paragraph 3.6 micro generation with an installed capacity of 30 MW will be well diversified in terms of unit size and geography and even if one or two units fail the majority of the capacity will be available to the power system. This can easily demonstrated through a simple statistical analysis.

Services

3.17 In order for the power system to operate correctly it also needs to be provided with services e.g. reactive power, synchronizing power etc. These services also need to be included in the total cost of producing energy. With very low levels of micro generation penetration – small fractions of 1% of power system generating capacity - in the power system it is unlikely that any services of significance will be provided. With higher levels of network penetration – greater than 1% of power system generating capacity – micro generation could contribute to providing services. However, only certain types of micro generation can provide particular services.

Additional costs

3.18 There may be some additional costs on the distribution network due to micro generation. For example these costs would include such things as voltage regulation and fault level changes required to accommodate micro generation.
IV THE ENVIRONMENT AND MICRO GENERATION

4.1 Broadly speaking micro generation is more environmentally friendly than large scale centralised generation and medium scale distributed generation. Also, because micro generation avoids the need for additional transmission and distribution capacity its environmental credentials are further enhanced. However, quantification of the economic costs and benefits to the environment of micro generation is best described as emergent.

4.2 Normally when electricity is produced from centralised power stations Carbon is emitted in the form of Carbon Dioxide (CO₂) and CO₂ is the main “green house” gas responsible for global warming. The only exception to this general rule is Hydro Electricity and electricity generated from Nuclear Power. Apart from being costly Nuclear Power also has other business and environmental issues associated with it. Hydro Electricity is very limited in terms of its application because of suitable sites and it also has environmental issues associated with it because of its impact on geography and communities.

4.3 In electricity production from fossil fuel the amount of CO₂ emitted depends on two parameters:

(a) The efficiency of the conversion process; and
(b) The fuel used.

4.4 The efficiency of the conversion process is directly related to the emission of CO₂. The higher the conversion efficiency of a process the less primary input energy is needed to produce a kWh of electricity and the lower the CO₂ emissions will be. The highest energy utilisation is obtained in combined heat and power (CHP) stations.

4.5 All micro generators that produce electricity from renewable resources, including sustainable biomass sources, are “Carbon free” electricity generators. That is every kWh produced is Carbon free and if it displaces energy produced from any fossil fuel plant it will reduce total CO₂ emissions.

4.6 Micro generators that produce electricity from fossil fuels – ignoring bio fuels – are again more environmentally friendly than centralised power stations if they operate in CHP mode. In this mode they are “Carbon abatement” electricity generators. This is because the heat produced in the production process is used at the site of the micro generator. This increased efficiency enables electricity to be produced with a smaller amount of CO₂ being produced.

4.7 Micro CHP (mCHP) has the potential to make a significant contribution to CO₂ reduction if it is applied to a mass market like the natural gas boiler market. This is well covered elsewhere and will not be discussed further here.

4.8 The full impact of the emissions targets agreed at Kyoto has yet to be felt, but a number of European governments have implemented pollution taxes, or incentives such as exemptions for improved performance. The UK already has a
Climate Change Levy (CCL) and Denmark has set a price of up to $13 per tonne for CO₂ emissions. It is likely that CO₂ emissions will become tradable therefore micro generation products will acquire increased value because of their ability to reduce CO₂ emissions. In January 2005 the EU Carbon trading scheme goes live.

4.9 The actual mitigation effect of micro generation will depend on the particular technologies installed and the generation mix they displace. On the assumption that it will be the most cost-effective form of emission reduction that will be implemented first, micro generation will initially displace the most inefficient and polluting existing generating plant. Therefore in E&W older coal plant without flue gas de-sulphurisation (FGD) will be displaced first.

4.10 Unlike centralised generation and the construction of transmission and distribution facilities, micro generation: -

(a) Needs no permitting or consenting;

(b) Does not suffer from the any “Not In My BackYard” (NIMBY) effects;

(c) Does not require a way leave; and

(d) Will not need a public enquiry.

4.11 There is little, if any, environmental impact from micro generation in terms of visual intrusion and emissions to land, air and water. However, micro wind, hydro and PV could be said to have some level of visual intrusion.

4.12 Finally, unlike other forms of centralised generation and transmission & distribution systems micro generation has no long-term implications for the environment e.g. storage, contamination, interference, visual intrusion, decommissioning etc.
V THE ECONOMICS OF MICRO GENERATION

5.1 Our economic analysis considers the costs of producing a kWh of electricity from a micro generator connected to the LV network under G83/1. We compared this cost with the cost of providing a kWh to a customer connected to the LV network. Under G83/1 connection is possible at three-phase or single-phase. Whilst we do not ignore a three-phase connection the vast majority of connections will be single phase. Essentially this means a domestic customer connected at 230 Volt single-phase with a standard 60 Amp or 100 Amp DNO service.

5.2 Using various data we examined:

- The capital costs of electricity production.
- The energy costs of electricity production.
- The delivery costs of electricity.
- The environmental costs of electricity production and delivery.

5.3 The total economic cost of providing electricity to customers on the low voltage (LV) distribution network is simply the sum of the above costs. We adopt this approach because it allows us to compare the economic costs of producing and delivering electricity. Our focus on costs excludes taxes, any profit or margin, licensed energy supplier’s other supply costs and metering costs. We also took no account of the time of day benefits attributable to micro generators.

5.4 We compared the costs of electricity production from new micro generators with the costs of electricity production from new base-load large-scale central power stations plus the costs of delivering the electricity over the transmission and distribution system. We included some environmental costs in our analysis and we based these on the emergent market for Carbon Dioxide (CO₂) trading.

5.5 This is a tough comparison but it is probably the easiest comparison to make and it uses recognised methodologies. Our comparison should be viewed with some caution because we are comparing emergent technologies with mature or learned out technologies.

5.6 Table 5.1 overleaf shows the total costs of providing electricity to customers on the LV distribution network. The table includes the costs of:

- (a) Production Costs in terms of capacity and energy;
- (b) Delivery Costs in terms of transmission costs and distribution; and
- (c) Environment Costs in terms of the difference in environmental costs between large centralised generation and micro generation.
## Table 5.1 – Total costs of providing a kWhe to a low voltage network customer

<table>
<thead>
<tr>
<th>Prime Mover</th>
<th>Capital Costs p/kWh</th>
<th>Electricity Costs p/kWh</th>
<th>Delivery Costs p/kWh</th>
<th>CO₂ Costs p/kWh</th>
<th>Total Costs p/kWh</th>
<th>Energy Utilisation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE µCHP 3 phase</td>
<td>3.30</td>
<td>1.99*</td>
<td>0.00</td>
<td>0.29</td>
<td>5.57</td>
<td>80</td>
</tr>
<tr>
<td>ICE µCHP 3 phase NSD</td>
<td>1.76</td>
<td>1.68*</td>
<td>0.00</td>
<td>0.27</td>
<td>3.7</td>
<td>85</td>
</tr>
<tr>
<td>ICE µCHP 1 phase</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Stirling µCHP 1 phase</td>
<td>2.20</td>
<td>2.28</td>
<td>0.00</td>
<td>0.29</td>
<td>4.76</td>
<td>80</td>
</tr>
<tr>
<td>Rankine µCHP 1 phase</td>
<td>1.76</td>
<td>2.46</td>
<td>0.00</td>
<td>0.29</td>
<td>4.5</td>
<td>80</td>
</tr>
<tr>
<td>PEM Fuel Cell µCHP 1 phase</td>
<td>18.64</td>
<td>1.82</td>
<td>0.00</td>
<td>0.00</td>
<td>20.46</td>
<td>80</td>
</tr>
<tr>
<td>SO Fuel Cell µCHP 1 phase</td>
<td>26.37</td>
<td>1.86</td>
<td>0.00</td>
<td>0.00</td>
<td>28.23</td>
<td>80</td>
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<tr>
<td>PEM Fuel Cell 1 phase</td>
<td>8.7</td>
<td>3.38</td>
<td>0.00</td>
<td>0.00</td>
<td>12.07</td>
<td>40</td>
</tr>
<tr>
<td>SO Fuel Cell 1 phase</td>
<td>12.3</td>
<td>3.86</td>
<td>0.00</td>
<td>0.00</td>
<td>16.16</td>
<td>35</td>
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<tr>
<td>µ Hydro 1 phase</td>
<td>2.7</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>2.7</td>
<td>67</td>
</tr>
<tr>
<td>µ Photo voltaic 1 phase</td>
<td>33.75</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>33.75</td>
<td>12</td>
</tr>
<tr>
<td>µ Wind 1 phase</td>
<td>4.63</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>4.63</td>
<td>40</td>
</tr>
<tr>
<td>CCGT</td>
<td>0.55</td>
<td>1.38</td>
<td>1.94</td>
<td>0.48</td>
<td>4.35</td>
<td>48</td>
</tr>
<tr>
<td>FGD Coal</td>
<td>0.67</td>
<td>0.84</td>
<td>1.94</td>
<td>1.20</td>
<td>4.65</td>
<td>30</td>
</tr>
<tr>
<td>Nuclear</td>
<td>1.32</td>
<td>0.31</td>
<td>1.94</td>
<td>0.00</td>
<td>3.57</td>
<td>29</td>
</tr>
<tr>
<td>Waste</td>
<td>1.98</td>
<td>0</td>
<td>1.94</td>
<td>0.88</td>
<td>4.8</td>
<td>26</td>
</tr>
</tbody>
</table>

Notes:
1. **Capital Costs** consist of capital remunerated at 5%.
2. **Energy Costs** consist of fuel costs. Running and fixed other works costs are excluded.
3. **Delivery Costs** are average use of system charges – Ofgem Structure of Charges document December 2000. T&D Loss assumed at 7%.
4. **CO₂ costs** - CO₂ priced at £12/tonne & Carbon burdens from defra web site.
5. **Energy utilisation** is the % of the primary input energy that is usefully used by the end user.
6. **µCHP** - Micro Combined Heat and Power. All µCHP is heat led.
8. **CCGT** - Combined Cycle Gas Turbine
9. **PEM** - Proton Exchange Membrane fuel cell
10. **SO** - Solid Oxide fuel cell
11. All ICE capital costs allocated to electricity production. In practice a proportion of these costs will be offset by avoided boiler capacity costs.
12. ICE Electricity costs calculated on a marginal basis. Only valid if ICE replaces boiler or is a very small part of the thermal capacity when working alongside an existing boiler.
13. Fuel costs - CCGT gas 20 p/Therm (0.76 p/kWh), domestic gas 1.35 p/kWh, coal £30/tonne including delivery, ICE gas 1.05 p/kWh - based on contract gas prices and Nuclear fuel costs 0.05 p/kWh excluding long-term liabilities & back end costs.
14. Costs of CHP units based on supply volumes greater than 100,000 units per year.
15. Fuel Cell prime movers are based on a 3kWe PEM or SOFC cell and are assumed to emit no CO₂. Supply volumes ca. 100,000 per annum.
16. No account of the time of day benefits attributable to micro generators.
17. Hydrogen for fuel cells is assumed to be “green Hydrogen”.

5.7 In Table 5.1 we excluded fixed other works costs, running other works costs and maintenance costs for large centralised generation. The table also excludes any maintenance costs for micro generation. We only recognised the environmental costs of CO₂. We ignored the costs of particulates, SOx and NOx. We recognised the cost of CO₂ as follows:
(a) CO₂ is priced at £12/tonne. This figure is taken from the UK CO₂ trading scheme. If a different price for CO₂ is chosen then the cost adders will change for all the thermal prime movers;

(b) CO₂ values for fuels are taken from defra’s environmental protection web site – Environmental Reporting, Guidelines for Company Reporting on Greenhouse gas Emissions; and

(c) CO₂ burdens are calculated using the CO₂ values for fuels at (b) together with the energy utilisation for each prime mover.

5.8 In practice the UK electricity generation-mix would be expected to produce electricity from a combination of prime movers. These prime movers will contribute varying amounts of CO₂ and therefore grid delivered electricity will have variable amounts of CO₂ associated with it because of the prime mover production mix.

5.9 The totals column in Table 5.1 excludes taxes, any profit; energy supplier’s other supply costs and any metering costs.

5.10 Table 5.1 only compares the costs of providing additional base-load kWh to the power system because this is the most stringent economic test. In other words, ignoring sunk costs, this is usually the lowest cost way of providing new kWh to the power system. Finally, Table 5.1 takes no account of micro generation providing services to the power system, such as synchronizing power. However, only certain types of micro generator can provide particular services.
VI CONCLUSIONS

Competitive Position

6.1 Broadly speaking we have shown that micro generation is potentially competitive with other forms of electricity production. However, the current institutional arrangements for electricity trading do not reward micro generation appropriately.

6.2 Moreover, the embryonic mechanisms that are beginning to emerge only potentially reward energy and rely on the development of a “competitive market”. Indeed current institutional arrangements and market mechanisms encourage the development of micro generation to displace kWh supplied to premises. In economic terms this is a perverse incentive and should be corrected because it will lead to sub optimal economic solutions.

6.3 Current institutional arrangements mean that only Licensed Energy Suppliers (LESs) can take any output from micro generators. Ultimately there will be significant competition issues associated with these arrangements because LESs are purchasing and selling at the same time from the same premise. Furthermore LESs could potentially influence the installation/non-installation of micro generation for their commercial benefit.

Economic Benefits

6.4 Micro generation delivers a range of economic benefits, in particular micro generation:

(a) Has major environmental benefits in terms of its potential to reduce the emissions of SOx, Nox, COx and particulates from electricity production;

(b) Has energy efficiency benefits;

(c) Will reduce the total capacity needed within networks, if micro generation coincides with peaks, because it will reduce the amount of electricity transported across transmission and distribution systems;

(d) Will reduce the amount of power system losses; and

(e) Will reduce the amount of large-scale centralised generating capacity needed on the power system, including reserves.

6.5 Mechanisms to access the benefits at (a) to (e) above either do not exist or at best can be described as emergent.

Diversity

6.6 Micro generation provides diversity both in terms of power (kW) and location (geography). Therefore micro generation has the capability to deliver a completely dispersed power supply to the power system.

Stranded Assets
6.7 The large scale introduction of micro generation might lead to stranded
distribution assets and eventually possibly transmission assets as well. However, recent work in the SIAM study (System Integration of Additional Micro-generation, September 2004, DTI contract DG/CG/00028/REP) concluded that the economic cost of accepting more than 17GW of micro generation into the British network is comparatively small and substantially less than the wider benefits that such a level of micro generation would bring. The SIAM study did not identify any issues with stranded assets.

Capacity

6.8 The potential speed of installation of micro generation represents a sea change in thinking as to whether or not in the short term both generating and network capacity is fixed. For example in the UK around one million gas-fired boilers are installed per annum. If only half of these boilers were micro CHP devices with an average capacity of 1 kW then 500 MW of electrical capacity would be installed per annum or around 10 MW per week.

Delivery/Use of System Costs/Charges

6.9 Starting from the position that micro generation reduces the overall cost of transmission and distribution one can either pass all of this benefit to the micro generator owner or one can share it in some way between all customers. At the extreme this sharing could be equally to all customers i.e. there is no special provision for micro generation owners but everybody benefits through the total cost of transmission/distribution decreasing.

6.10 It is clear that when micro generated units of electricity are exported onto the LV network there are market failings in terms of cross subsidies and cost allocation. These market failings need correction to allow a rational outcome that more accurately reflects what is actually happening to micro generators units of electricity. If the customer next door is not charged the full cost of transmission and distribution for micro generator's units of electricity then the saving will not accrue to the micro generator owner.

6.11 The portion of the distribution operator’s network that is directly impacted by micro generation appears to be less than 10%. It is therefore clearly iniquitous to charge full delivery costs for micro generator’s units. It is equally wrong to allow Licensed Energy Suppliers to take benefit by charging full price for the units they have obtained on the LV system.

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