The Value of Microgeneration

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Financial support mechanisms can be argued to be of value as a short term measure to offset perceived imbalances in markets, to reward genuine, but otherwise unrecognised values for as long as those market failures persist, but also as a short term expedient to stimulate the market for a promising technology in the expectation that this will more effectively add scale and consequently drive down prices to a sustainable level.

The economics of microgeneration are almost invariably assessed on a rather simplistic assessment of end-user payback, which considers the recovery of the initial capital investment from the net income generated by the microgeneration technology offset by additional operation and maintenance costs, but takes no account whatsoever of the benefits or costs[1], nor indeed of any disbenefits, which accrue to the wider energy system.

Clearly, in order to optimise utilisation of our constrained resources and encourage cost effective investment in a sustainable energy system we need to be able to attribute both costs and benefits of any given measure appropriately.

End-user economics

When considering the economic viability of micro CHP from the point of view of the end-user, it is the marginal capital cost over and above that of a replacement gas boiler as well as the marginal operating benefit which concern us.

In this case a micro CHP system with an installed cost of say £4000[2], compared with the alternative of a gas boiler costing £3000, incurs a marginal investment of £1000 which must be recovered from the operating benefits[3].

At current electricity and gas prices, for each unit of electricity produced, micro CHP generates a net saving to the householder of 8p/kWh, assuming that the electricity is consumed by the householder rather than exported. The marginal investment of £1000 would be recovered after 12,500 hours of operation, equivalent to around 3 years for a large family home.

However, this value is based on the assumption that the electricity generated displaces that which would otherwise have been purchased at the fixed domestic tariff, which does not necessarily reflect the true value of energy at any given time, being instead a demand weighted value for a representative consumer with a standard consumption profile and *without any form of microgeneration installed*.

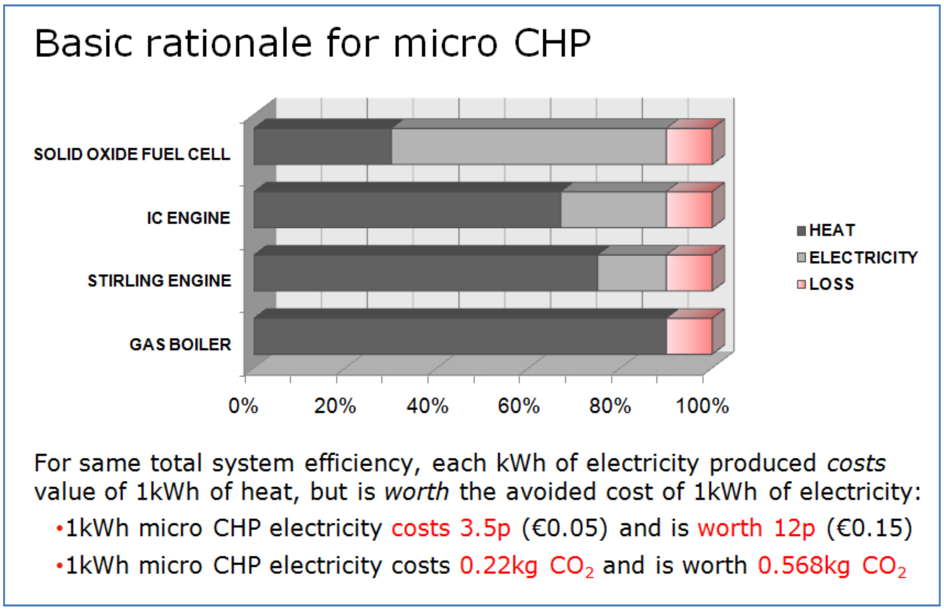

Figure 1 Economic and environmental rationale for micro CHP

Several commentators have not unreasonably noted that this value is an inappropriate metric for value and is used only due to the crudity of the present trading and settlement arrangements for NHH (Non Half Hourly) metered customers. In some cases this will advantage the technology, as in the case of PV where the generation is predominantly in summer during periods where electricity has relatively low value, in others such as micro CHP it will disadvantage the technology which generates electricity during winter evening periods when the power has a very high value, often higher than the retail tariff.

Market failures and obstacles in the energy system

It may be appropriate for an energy system entirely predicated on central plant generating at high voltage and distributing power down through successive voltage levels to the end user, that the cost structure reflects this paradigm.

As a consequence of the rather crude settlement system currently in place for domestic (NHH) consumers which is an inherent component of this obsolete paradigm, the values outlined above represent the only ways in which it is possible to recover the householder’s investment in microgeneration. However, this approach fails to recognise the intrinsic or potential additional value of microgeneration and serves neither the microgeneration operator nor the energy system as a whole.

There is a wide range of potential sources of value arising from microgeneration which are attributable to either the householder or the energy system as a whole. But how do we address the challenge of fairly rewarding microgeneration operating within the current paradigm, without imposing undue penalties on the remainder of the energy system?

The value of generation capacity

Even before the government announced its ambitious targets for decarbonising the energy sector by transferring the burden of domestic heat and personal transport to the electricity sector, the constraints of our current energy market were expected to lead to a significant generation capacity shortfall somewhere around 2015. This was primarily due to thermal plant closure plans resulting from EU emissions legislation[4] and the end of life of the bulk of our aging nuclear fleet. The level of this shortfall remains open to debate, but DECC[5] is expecting 20GW of closures within the next decade, and one industry leader[6] expressed the view that we would face a shortfall of 36GW representing 45% of our current peak capacity before 2020.

The graph below showing average UK daily heat and power demands illustrates the potential increase in electricity demand if the demand for heat, currently met largely by gas heating, is to be met using electric heat pumps. Assuming an optimistic COP[7] of 3, the heat demand of 120GW would be equivalent to an electricity demand of 40GW, ultimately doubling our current capacity requirements even assuming that some form of DSM (Demand Side Management) can limit the peak power demands within each daily period.

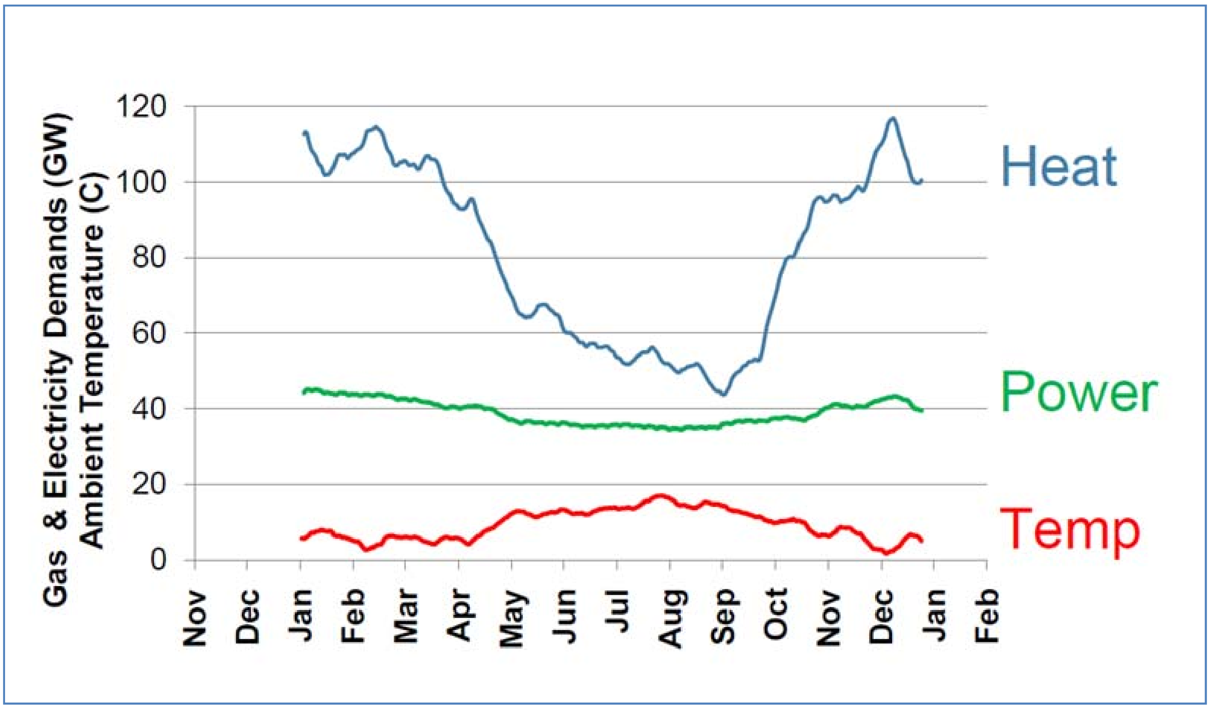

Figure 2 UK daily average heat and power demands (Source: ETI)

At the same time, uncertainties regarding future legislation, on emissions for example, as well as capital constraints and an inherent risk aversion in the electricity industry, have led to a very limited central power plant new build programme to fill this looming capacity gap.

Various solutions to this dilemma have been proposed including a change to the way in which generators are rewarded. There are already mechanisms in place to reward flexible plant operation for providing rapid response to grid operator demands for increased or reduced generation which will be discussed below in the section on ancillary services. However, proposals now being considered[8] include the option to provide both a payment for energy (MWh) generated and supplied to the grid as at present, and an additional amount for the available capacity (MW) connected to the system, known as Capacity Remuneration Measures (CRM).

This could lead to an extraordinarily complex mechanism if the characteristics of each generation type were to be taken into account; it would be necessary for example to evaluate the potential of each individual power plant in terms of maximum capacity, ramp rates (positive and negative) as well as minimum operating levels and a whole host of key parameters. It would also, most significantly for microgeneration, need to take account of the location of such capacity within the network for, if the capacity shortfall arises as a consequence of demand from domestic heat pumps, then capacity is required at the low voltage (400V) level.

One additional point often overlooked with highly distributed microgeneration is the provision of a robust and secure supply. Whilst many consider micro CHP as an unproven means of providing large scale generation, it is clear that, on a stochastic basis, having many millions of small generators, distributed throughout the network is significantly more resilient as generation capacity than a single large generator.

And, given the NIMBY response to even the most benign generation plant whether it be biomass, hydro or wind, the ability of micro CHP to provide additional incremental capacity without giving rise to any visual or other planning objections, is a major factor in its favour.

One more challenge for any large new build plant is the "boom-bust" cycle outlined by BCG[9], in which new capacity is built in response to a capacity shortfall in a market which has led to high prices. This price signal tends to result in significant new capacity becoming available within a relatively short period leading to a substantial drop in power prices and bringing the economic viability of the new plants into question. Micro CHP, which provides incremental rather than step change capacity increases avoids this phenomenon altogether.

Quite how we quantify the value of capacity from any source is controversial to say the least, but whether we attribute the minimum proposed level for maintaining conventional coal at £50/kW or at the likely cost of nuclear new build at £3,500/kW and rising, it is clear that there is some, currently unrecognised value in micro CHP capacity.

Generation profiles for microgeneration technologies

The generation profiles of microgeneration technologies vary considerably, and clearly the nature of each profile will result in different output weighted values. Engine-based micro CHP which, without intervention generates power in response to heat demand in the home, tends to generate when demand from the household is at its maximum and any export provides a valuable addition to a highly stressed system when demand is at its peak. It is thus inherently peak following generation on an aggregate basis; some fuel cell micro CHP technologies may follow a similar generation profile, although the very high electrical efficiency SOFC micro CHP technologies will tend to operate as continuous baseload. However, as can be seen from the figure below, even the engine based technologies which may match the overall daily household consumption, may export some of their generation for short periods even during the same half hour trading period that they are also importing power. This may be overcome by the application of electricity storage which not only tends to avoid export, but also offers the potential for significant additional value discussed further below.

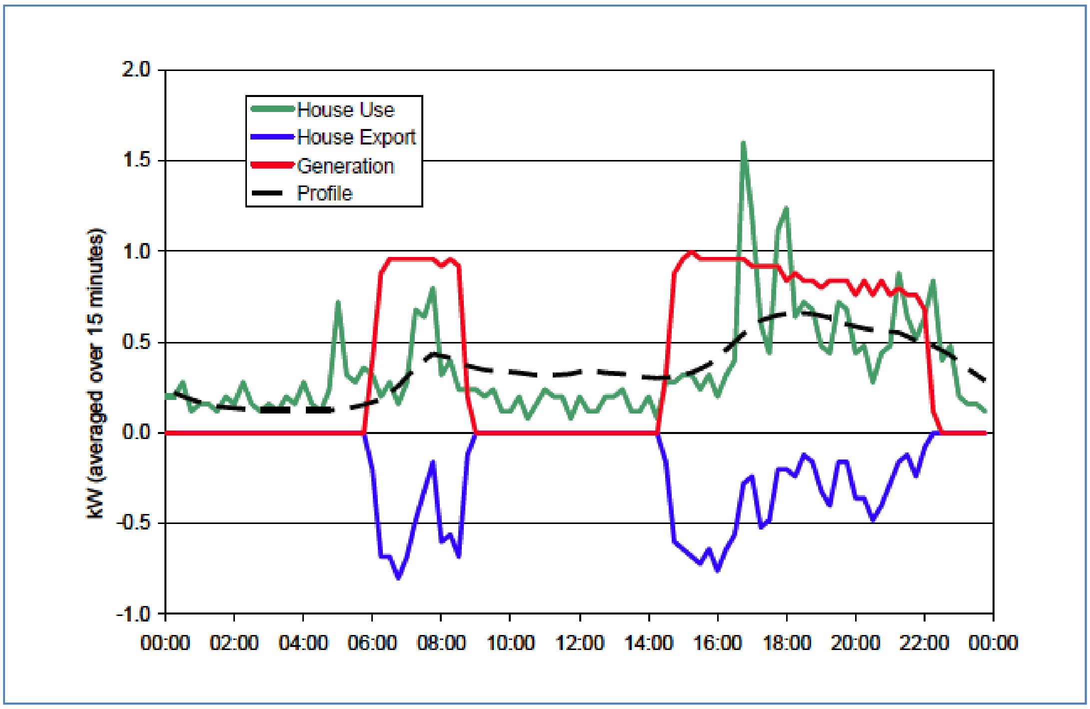

Figure 3 Volatile domestic consumption profile causes import and export even during periods of generation

As a baseline for evaluating the overall value and as an illustration of the current market failure to recognise it, the table below[10] shows a representative calculation of end-user economics for a micro CHP system installed in a typical UK family home. Based on an annual consumption of 6000kWh (typical of the larger homes for which micro CHP is intended) and with a margin of 0.5p/kWh, the energy supplier would expect to make around £30 annually from each customer. Once the household is equipped with micro CHP they would expect to reduce their import significantly resulting in a margin for the supplier of only £21. However, the "real" cost of supplying the same household based on the revised consumption profile which now substantially avoids import during peak price periods, would be only 9.5p/kWh, resulting in a doubling of the margin on each unit of electricity supplied. In the case of the export which is probably worth the 5p/kWh paid by suppliers such as E.ON for micro CHP customers (prior to introduction of the Feed In Tariff), the supplier has no mechanism at all to trade this electricity at a viable transaction cost[11] and is therefore simply subsidising the customer.

It can be seen that the reduction in the householder's energy bill is achieved at the expense of the energy supplier in the absence of an appropriate tariff regime. If and when this imbalance can be resolved using suitable metering and settlement processes, both the end-user and the energy supplier benefit; the householder receives the same savings, but the supplier's margin is enhanced.

	Boiler/grid	mCHP TODAY	mCHP REAL PROFILE
Import tariff (cost) p/kWh	10.5 (10.0)	10.5 (10.0)	10.5 (9.5)
Annual import kWh	6000	3758	3758
Electricity bill (profit) £	633 (33)	397 (21)	397(40)
Export tariff (value) p/kWh		5 (0)	5 (5)
Export total kWh		961	961
Export profit (loss) p/kWh		(48)	0
Export payment to customer £		48	48
Total energy bill (profit) £	1504(59)	1341(2)	1341(69)

Illustrative costs based on annual heat loss 23000kWh; electricity consumption 6000kWh
January 2010 energy prices

Figure 4 Energy bill savings from micro CHP

Enhanced utilisation

In order to maximise the value of power generated within the home, it is possible to store the electricity for example in batteries; this can be achieved for any domestic generation including wind, PV and micro CHP.

It is also possible to decouple the power generation from the heat demand in the case of micro CHP in much the same way as large CHP community heating schemes in Scandinavia operate during peak power periods and store any heat not immediately required in large thermal reservoirs.

However, in both these cases although the value to the consumer is maximised, this “value” is derived from the difference between the export tariff (if any) and the import tariff. As the import tariff does not necessarily reflect the actual value of the energy content at that moment, and includes a socialised DUoS component, it may be considered that the value is effectively a cost imposed elsewhere in the system and paid for by others who gain nothing from the transaction. It is, however, today the only way of enhancing the householders’ utilisation value.

The exploitation of this anomaly is not only an unfair burden on the system, but also fails to capture more significant value from other sources which provide a truly value added service.

For example, these same storage technologies might also be utilised to optimise the individual system for trading purposes that is, storing the power generated during periods of low value, for later use during periods of high system value. Although apparently the same as tariff optimisation, in this case the wholesale trading optimisation has a real value being a reflection of the system's ability to deliver power at any given moment.

In the case of energy storage as electricity, careful consideration needs to be given to the storage capacity (kWh) and charge and discharge rates (kW). Clearly the battery can only be charged at the output rate of the generator (unless simply importing grid power) but the discharge can be set at almost any level. Battery systems are thus far more flexible than thermal storage systems which are only able to charge and discharge at the output of the generator and tend to be considerably bulkier than equivalent battery storage. However, thermal storage is an essential component of a micro CHP system so imposes no additional cost for this service, other than the control system itself.

The value of storage systems to the householder purely in terms of utilisation is constrained by the amount of exported power which can be effectively stored and used later to displace imported power. Depending on the energy so generated, this could be as much as £150 per year although for homes monitored during the Carbon Trust field trials[12], the majority had a potential value in the range of £30-100.

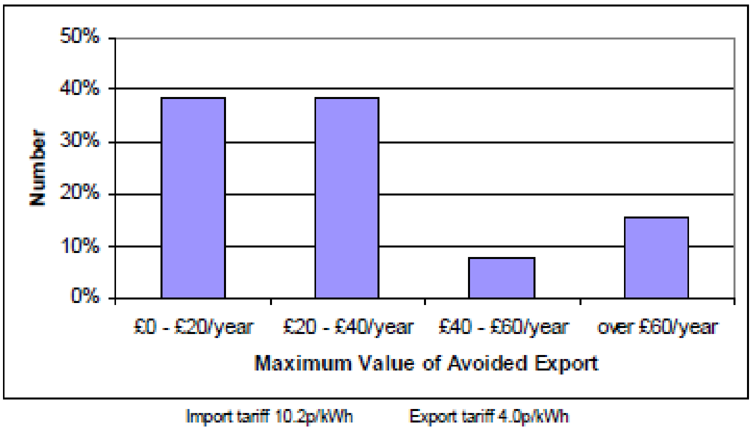

Figure 5 Tariff value of load shifting for domestic consumers

Carbon emission savings

As shown above (Figure 1) the carbon saving of micro CHP derives from displaced central plant generation. Each unit of electricity generated by the microgeneration unit has an environmental cost associated either with the input fuel or the embodied energy in its production. For gas fired micro CHP this cost is typically 0.23kgCO_2/kWh and for solar PV around 0.25kgCO_2/kWh[13]. Against this is the saving in central plant emissions which is discussed in detail elsewhere[14]. Depending on the carbon intensity of the central plant, an engine based micro CHP unit operating 3000 hours annually might expect to displace 1740kgCO_2 worth between £28 and £122 for carbon values of £16 and £70 per tonne respectively[15], a value which is impossible for the householder to capture. For SOFC technologies running continuous baseload, although the specific carbon intensity of the displaced central plant is lower, the longer running hours result in annual savings of 4555kgCO_2 worth between £73 and £320.

On a kWh basis the displaced carbon is worth 1.0-4.1p/kWh of generation at a carbon price of £16-70/tonne respectively.

In addition there is an indirect carbon benefit attributable to micro CHP as a DSM technology discussed below.

	kgCO2/ kWh	NET SAVING	ANNUAL SAVING (kgCO2)	ANNUAL SAVING (kgCO2)
			3000kWh	8760kWh
UK AVERAGE (ASSUMED POLICY VALUE)	0.43	0.21	630	1840
SAP 2005	0.57	0.35	1044	3048
ACTUAL UK AVERAGE 2009	0.51	0.29	870	2540
AVERAGE MARGINAL	0.69	0.47	1410	4117
PEAK MARGINAL	0.74	0.52	1560	4555
AVERAGE MARGINAL PLUS LOSSES	0.74	0.52	1560	4555
PEAK MARGINAL PLUS LOSSES	0.80	0.58	1740	5081

Figure 6 Carbon displaced by micro CHP

Ancillary services

Although no microgeneration technology inherently lends itself to the provision of ancillary services and certainly not at a scale which could be cost effectively traded, it is theoretically possible for a service intermediary to aggregate a substantial fleet of microgeneration systems for one or more of the currently traded ancillary services, albeit with the addition of either electrical storage or power conversion components. However, given the current inclination of some microgeneration owners to invest in electrical storage to optimise the value of their generation by maximising utilisation, it would seem desirable to make use of that investment to capture additional value streams wherever possible.

Some services such as STOR (Short Term Operating Reserve) could also be delivered using thermal storage as a proxy for electrical storage as noted above for load shifting purposes subject to suitable sizing of the store and the heat to power ratio of the micro CHP technology being considered.

System balancing

A 2006 study undertaken on behalf of DTI[16] evaluated the financial and environmental benefits of micro generation as a form of DSF (Demand Side Flexibility) and identified significant potential value.

One major benefit of DG or any other DSF measure compared with part loaded coal plant is that emissions penalties from spinning reserve are avoided. Thus there is both an economic and environmental advantage attributable to micro CHP as a DSF measure over and above the current tradable value of standing reserve. This was estimated at 0.08-0.17tCO_2/MW/h or 300-700tCO_2/MW/year for a 4000hour contract window worth £20-35/kW annually just for the emissions reduction.

In addition, the provision of contingency reserves might save 1.2tCO_2/MW/day compared with warming a coal fired plant, worth an additional £7/kW annually. The study concluded that for an installed fleet of 2GWe equivalent to around 2 million 1kWe micro CHP units, net system cost savings of £10-70 million annually could be achieved and emissions savings of 1% of the total UK allocation of 130 million tonnes realised from this application alone, that is ignoring the simple displacement of emissions from central plant during everyday operation outlined earlier and worth up to 4p/kWh.

Further, their analysis of generation capacity cost savings amounted to £60/kW per year. Taken together, the carbon, system balancing and capacity values identified in this study amount to £135 per kW annually, equivalent to 4.5p/kWh of micro CHP generation.

However, as a note of caution, although such capacity benefits might be achieved if electrical storage were included as a component of a micro CHP system, only a reduced capacity would be stochastically available based on a fleet of installations utilising for example thermal storage as a proxy for electricity.

Frequency response

Frequency response is the first measure taken to balance supply and demand on a short term basis. Neither primary nor secondary frequency response could be provided by microgeneration systems alone; both could be provided by microgeneration systems incorporating electrical storage. However, the value of this service alone could well justify investment in electrical storage at household level. Even a modest 500Wh battery with a discharge rate of 1kWe could recover £66 and a larger 2500Wh battery with a discharge rate of 5kW as much as £329 annually[17]. The provision of this service would still leave room for the provision of additional services from the same device.

Reserve

The next level called upon is fast reserve which acts within 2 minutes and operates for up to 15 minutes. Given appropriate electrical storage, microgeneration could provide this service quite readily, although most engine-based micro CHP technologies would not reach full output within this period.

STOR acts within 2 hours and operates for up to 2 hours. If the micro CHP system was able to serve a heat demand throughout this two hour period it would be possible to provide the service without the need for any storage. However, it is unlikely that this would be the case, for if there were a heating demand at that time, it is most likely that the micro CHP would already be running. Furthermore, even if thermal storage were in place, it would need to be fairly substantial to accept the thermal output of the engine in the absence of any thermal demand from the household. For this application then it is likely that electrical storage would be required; the larger battery referred to above could expect an annual value of £26 for a 1kW discharge rate.

Implications for distribution and transmission networks

So far we have considered only values arising from energy production whether in terms of generating capacity, emissions reductions or primary fuel savings. However, of perhaps equal importance is the impact of microgeneration on the networks.

The SIAM study[18] in 2004 not only considered the system balancing benefits discussed above, but also examined generic network configurations of low medium or high load densities, each with varying levels of microgeneration penetration in order to identify potential technical issues as well as economic impacts. The study concluded that significant benefits accrue to the energy system by the widespread installation of micro CHP products even though the value of these benefits is not attributed to the owners and operators of micro CHP.

These are inherent values resulting from the deployment of micro CHP and do not include the potential additional values which be result from active management of micro CHP fleets outlined above. The values arise from:

- Reduced network losses due to location of micro CHP within the low voltage distribution grid.
- Avoided CAPEX investment in the LV distribution networks
- Reduced cost of holding capacity due to the coincidence of micro CHP generation with peak winter loads

- Reduced primary energy costs within the UK electricity sector
- Avoided emissions costs.

An update of the values[19] identified in the SIAM report indexed to 2011 prices concluded that these savings represented a value of 6.2p/kWh of electricity generated by micro CHP.

Although the SIAM study outputs were based on modelling rather than measured impacts, subsequent field trials seem to support the conclusions. For example, the study noted both the excellent match between micro CHP generation profiles and system demand and the likely flattening of system load profile which was expected to reduce the need for reserve and for part loading. Field trials of micro CHP systems within a large housing development showed this characteristic was indeed valid for real micro CHP installations[20].

Experience in the Netherlands with high penetration of WhisperGen micro CHP units[21] confirmed that the network was able to accommodate the technology without adverse impacts and studies by UK DNOs have found that, although some microgeneration technologies such as PV can cause adverse effects during summer peak generation periods, the same is not true for micro CHP. Indeed at least one DNO has considered the possibility of using islanded fleets of micro CHP units to maintain supply during planned outages, adding further to the value of micro CHP by minimising system downtime.

Summary of value arising from micro CHP generation

The values arising from the generation of electricity by micro CHP within the home identified above fall broadly into three categories.

The end-user economics which are based on apparent value to the micro CHP operator, but which do not effectively reflect the true value of the generation or the customer and indirectly impose unfair burdens on other system users. On this basis we have seen that a typical customer might expect to make energy bill savings of £200 per year without direct subsidy and up to £500 with FIT at current levels of 10p/kWh.

Inherent system benefits including capacity, avoided emissions, efficiency and other operational benefits conservatively estimated at between 7-12p/kWh generated, equivalent to an annual value of £210-360. This value is a socialised system benefit and is in addition to any savings delivered to the householder.

Further value derived from the provision of ancillary services which will become increasingly valuable as the UK energy system becomes dependent on intermittent RES generation currently amounting to more than £300 annually for a 1kWe system.

Conclusion

In order to fairly capture and attribute the direct end user value of micro CHP generation and incentivise operational optimisation, fundamental changes are required to be made to the settlement system. These should include the ability of individual consumers to be billed on a true profile basis without the current excessive transaction cost.

Furthermore, in order to capture additional societal values such as carbon emissions reduction, capacity, and ancillary services, intermediaries will be required both to act as aggregators and to optimise the operation of a substantial fleet of micro CHP units.

Both will require the development and roll out of appropriate communications and control hardware and software to support such functionality, integrated within the individual home and the legacy utility systems[22].

Given the current energy system and regulatory and infrastructure built around it, it is unlikely that such changes can be made for several years, possibly more than a decade[23]. However, it is imperative that we begin to address these issues now if we are ever going to obtain the best value from our finite resources.

The apparently generous FiT of 10p/kWh delivering a payment of £300 annually does not reflect the real system value noted above. However, in the short term it would appear that the FiT albeit a blunt instrument which neither incentivises resource or performance optimisation, represents a pragmatic proxy for the value of micro CHP.

References & Notes

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[1] For example, in just the same way that a householder may install an electric heat pump without concern for the burden this may impose on the nation’s generation or distribution infrastructure, so micro CHP receives no reward for offsetting this same burden.

[2] Target price once mass market production volumes have been reached. Current small volume production results in an unsubsidised fully installed cost of between £7-10,000.

[3] The alternative scenario of a discretionary replacement of a gas boiler would require the full installation cost as well as the higher resultant savings to be considered. However, although it may result in a positive investment case for the householder in some instances, this scenario presupposes that householders will replace perfectly adequate, but possibly very inefficient, gas boilers which may not result in optimum use of capital resources.

[4] LCPD (Large Combustion Plant Directive) required all coal fired plant to comply with severe emissions standards (which many were unable to do economically) or to “opt out” and commit to a limited number of run hours prior to closure. Depending on the capacity factors selected by the operator, it is expected that most of these hours will have been used by 2015-16.

[5] *Planning our electric future: a White Paper for secure, affordable and low-carbon electricity*, DECC, July 2011

[6] Paul Golby, CEO E.ON UK June 2008 reported in The Telegraph

[7] COP is Coefficient of Performance, an indication of the effectiveness of a heat pump in producing heat from electricity input. It is the ratio of output heat to input electricity, so that a COP of 3 means that for every kWh of electricity supplied to the heat pump, 3 kWh of heat will be delivered to the home.

[8] *Planning our electric future: a White Paper for secure, affordable and low-carbon electricity*, DECC, July 2011

[9] *Keeping the lights on*, Boston Consulting Group, May 2003

[10] 2010 prices; additional value of each kWh generated by micro CHP indexed to November 2011 prices would be around 1.2p/kWh.

[11] *Microgeneration & Billing*, Jeremy Harrison, CRM, Billing & Metering Conference Amsterdam 2008

[12] Carbon Trust micro CHP Field Trial Report 2011

[13] *The energy intensity of photovoltaic systems*, (updated to 2011 wafer thickness and UK conditions) Blakers & Weber, Centre for Sustainable Energy Systems, Canberra, October 2000

[14] *The role of micro CHP within a decarbonising energy system*, Jeremy Harrison, COSPP June 2011

[15] DECC Carbon Floor Pricing proposes £16 (2011) rising to inflation adjusted £70 in 2030

[16] *Reducing the cost of system intermittency using demand side control measures*, IPA Consulting, Econnect, Martin Energy for DTI 2006

[17] *Electrical Storage for micro CHP*, EA Technology 2007

[18] *SIAM (System Integration of Additional Microgeneration)* Mott MacDonald for DTi, 2004

[19] *Micro CHP as an integral component of the UK's energy strategy*, JDS Associates, November 2011

[20] *The Performance of an LV network supplying a cluster of 500 houses each with an installed 1kWe domestic heat and power unit* CIRED May 2007 Vienna Beddoes et al

[21] *What is the impact of high concentration of micro CHP's on the low voltage grid?* Marcel van Hest, NUON Tecno, Transmission & Distribution Europe, Prague March 2007

[22] Examples of this technology include HOMA (www.homa-sw.com) which has been demonstrated with Dutch and UK utilities.

[23] *Microgeneration & Billing*, Jeremy Harrison, CRM, Billing & Metering Conference Amsterdam 2008