Modern Power Systems
Microgeneration article

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What is Microgeneration?

The UK Government definition of Microgeneration[1] applies to a rather surprising mix of heat and power technologies with a thermal output below $45kW_t$ or an electrical output of $50kW_e$. It covers electrical generation from wind, solar photovoltaics (PV) and hydro, heat generation from biomass, solar thermal and heat pumps as well as micro CHP which produces heat and power from renewable or fossil fuels. It is not just another term for small scale renewables, but comprises a portfolio of low carbon technologies.

There has been a tendency amongst advocates[2] and sceptics[3] alike to lump all Microgeneration technologies together, either as “all good” or “all bad”. This is particularly unhelpful when attempting to understand the potential contribution Microgeneration can make to UK energy strategy and it is important that we understand the particular characteristics and potential role of each technology.

The purpose of this paper is to examine these characteristics and the relative merits of the main technologies included in the scope of Microgeneration.

The potential for Microgeneration

A study commissioned by the Energy Saving Trust (EST) in 2005[4] concluded that up to 25% of the UK energy supply could be met from Microgeneration by 2050, without Government subsidies, based primarily on micro CHP and micro wind. Other studies[5] have indicated a wide range of potential contributions, with micro CHP alone potentially providing an installed capacity of 12-22GWe. The EST study was clear in identifying technologies which were expected to contribute to this overall potential and avoided the assumption that Microgeneration was good or bad per se.

Microgeneration enthusiasts who would promote all Microgeneration technologies equally, fall into the same trap as advocates of central plant who contend that Microgeneration is at best a distraction and at worst a white elephant simply because one or two Microgeneration technologies are not yet optimal and that all central plant solutions are inherently better.

Although the PIU review and the EWP (Energy White Paper) 2004 assessed the carbon mitigation benefits of micro CHP separately, the EWP 2007 (see Figure 1), lumps all heat producing Microgeneration together so that heat pumps (which are cost effective) are combined with solar thermal (which is not) and all electricity producing Microgeneration together so PV (with a carbon mitigation cost of £520-£1250) is combined with micro CHP (with a cost of minus £630 per tonne)[6]. Not surprisingly, Microgeneration appears as a poor option in this bizarre analysis. To mix PV, arguably the least cost effective carbon abatement technology with micro CHP which, according to EWP 2005 is the most cost effective alongside energy efficiency is patently ridiculous.

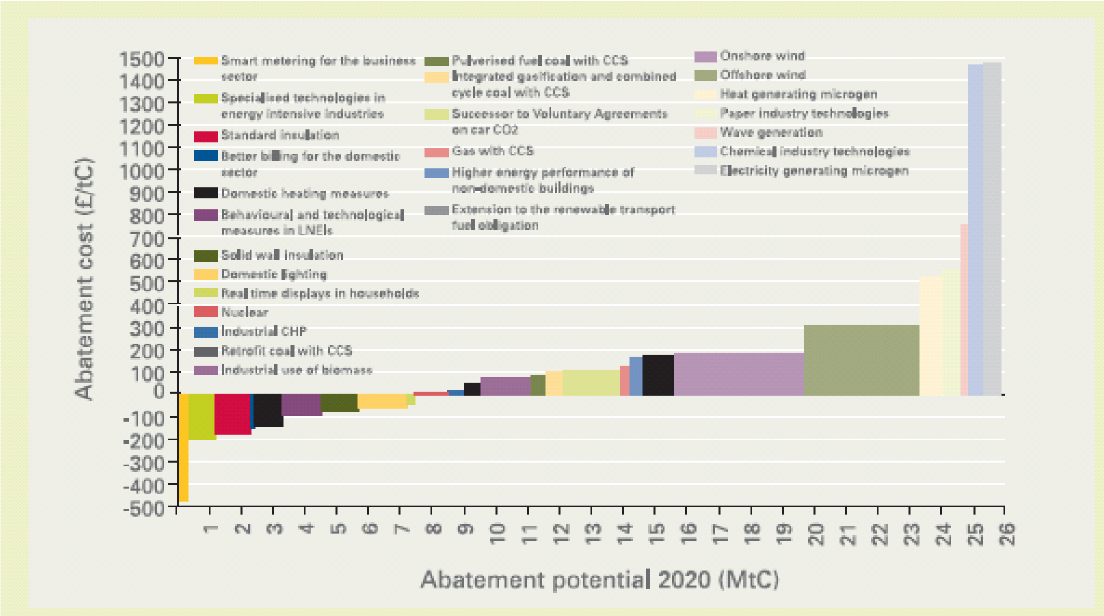

Figure 1: marginal abatement cost curve (source: EWP 2007)

The distortions arising from this simplistic analysis are compounded by the development status of different Microgeneration technologies; some are mature and have demonstrated their potential performance and production costs, whereas others are at their earliest stages of market entry and are still relatively expensive and may not perform to their ultimate potential. Commentators like George Monbiot, normally a staunch advocate of environmentally benign solutions, are sceptical of the whole Microgeneration industry on the basis of the over-hyped performance of a few fashionable technologies[7]. The questionable performance of micro wind, for example, has also cast doubts on the demonstrated performance of micro CHP. This latter technology is currently produced in small volumes, but is likely to become significantly cheaper over the next few years as it enters mass production; at the same time (electrical) efficiency levels currently at around the 10% mark, are likely to rise considerably as other products become available, with fuel cell based systems in the next decade or so expected to achieve electrical conversion efficiencies of over 40%.

Microgeneration generic benefits

Microgeneration can, in its own right, deliver carbon savings, contribute to long term security of supply and help tackle fuel poverty. It will help avoid single fuel dependency and add diversity to complement large scale intermittent sources, acting as an enabler for high penetration levels of, for example, large scale wind. It will also help to minimise system losses, although that is of less relevance if Microgeneration is significantly less efficient than large scale RE.

So, although Microgeneration is no silver bullet, it does have a significant role to play as part of a mix of heat and power producing solutions. A number of studies, with a particular focus on micro CHP, have shown how Microgeneration can help deliver all four of the key policy objectives in UK Energy Policy. The results are surprising, in that the benefits identified generally exceed the earlier claims made by manufacturers. Three studies in particular show that micro CHP makes a substantial contribution to fuel poverty, carbon mitigation and diversity of supply targets.

A Policy Studies Institute paper[8] shows that mCHP contributes almost as much to fuel poverty as all other measures put together including mCHP. This paradox is explained by the fact that, if homes are well insulated, the reduction in thermal load leads to a reduction in electricity production and hence makes it unlikely that micro CHP would be installed in as many homes: *"Micro CHP can do almost as much for fuel poverty as making all possible energy efficiency improvements, including micro CHP."*

A report by the consultancy Ilex, shows that appropriate emission factors to be used for calculating CO_2 displacement for the next 10 years[9] are actually higher than both that of the average generation mix and of current marginal generation emissions. Current government policy is based on 0.43kg/kWh which is the average mix, a somewhat arbitrary and in this case, inappropriate measure. Micro CHP is shown to displace marginal plant and the study, which matches actual generation profiles for installed WhisperGen units against marginal plant, shows a displacement of 0.54 rising to 0.67kg/kWh by 2010. This counter-intuitive result is the consequence of the increasing cost of coal-fired generation which, although it reduces the total amount of coal generation in the overall mix, shifts all coal generation into the margin.

Further indirect benefits accrue to micro CHP as it has a profile which supports intermittent wind resources and, by nature of its diversity, reduces the need for back-up capacity. The ECI study[10] based on 20 years of wind and consumption data, concludes that only 400MWe back-up capacity would be required if micro CHP were to support 10GWe of wind generation.

The SIAM[11] (System Integration of Additional Microgeneration) study was expected to identify adverse impacts of large-scale implementation of micro CHP on Distribution Networks, potentially requiring significant investment in network upgrades. In fact, the study showed that in only a few extreme cases would micro CHP incur additional short term costs, that in the majority of cases it would have beneficial impacts and the overall benefit to the UK distribution network was substantial; savings in deferred network upgrades and improved operational efficiency were estimated at up to £1.2 billion by 2020 assuming a high penetration level of Microgeneration.

A fundamental attribute of Microgeneration is that it will, by definition, be introduced incrementally, avoiding catastrophic financial and technical risks and delivering real carbon and financial savings from day one. Other potential carbon mitigating solutions, such as nuclear, involve step changes in capacity and will not deliver any benefits for as much as a decade; it is a substantial risk to attempt to anticipate what market conditions might pertain in 10 years when it comes on line, still less over the subsequent 40 years or so life of such plant.

It is, therefore, inappropriate to consider Microgeneration as just another generation option in the same way as central plant alternatives. If we invest in a CCGT plant to replace an existing obsolete plant, that is not the same as incrementally eroding the demand for marginal plant. The former may (as in the case of nuclear) demand to be run as baseload and will thus displace baseload or "must run" plant such as renewable wind; in this context nuclear is displacing zero carbon generation. Microgeneration by contrast (specifically micro CHP which is largely peak-following) will displace marginal plant, with consequently high financial and carbon benefits.

Some advocates of Microgeneration cite the benefits of public engagement, and it is clear that householders who invest in Microgeneration do become more conscious of their overall carbon footprint and tend to modify their lifestyles to further reduce their environmental impact. However, there is a limit to how much value should be attributed to this, particularly if the technologies in which they invest are subsequently shown to be significantly less effective than larger scale alternatives. An example of this is the current fad for micro wind which, even at the optimistic cost of £1500 for a 1kWe unit is far less effective than investing a similar amount in a large scale, say 2MWe, product which will have a yield of an order of magnitude higher, even accounting for transmission & distribution losses.

Microgeneration technologies

As mentioned earlier, Microgeneration can be considered to comprise three main types of technology, heat producing, electricity producing and heat and electricity producing. Heat producing technologies have a particularly important role to play as, at the domestic level, 85% of energy consumption for a typical household is for the production of space and water heating. Even allowing for the reduction in space heating demands for new homes, water heating will remain a significant demand; space heating for the existing 24 million homes will also remain.

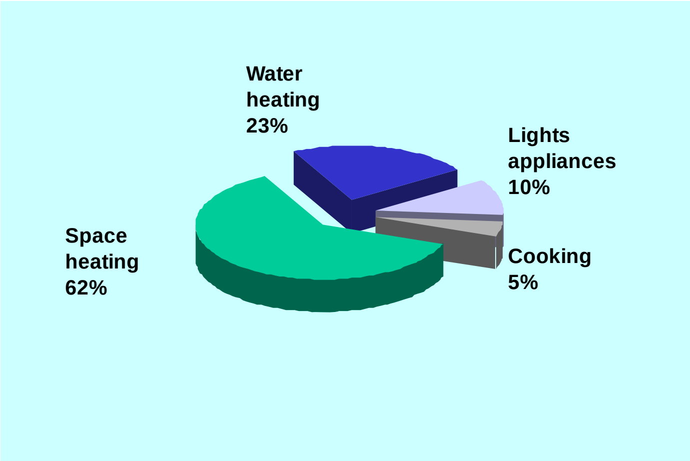

Diagram: Energy use within the home [12]

In general, electricity only production technologies are discretionary, that is to say that they are an addition to the existing domestic energy system. They are thus penalised by the fact that their entire cost has to be recovered by the energy savings they generate, unlike biomass boilers, heat pumps or micro CHP which only need to recover their marginal cost over that of a conventional oil or gas fired boiler. An additional challenge is that the electricity may not be generated at the time it is required and thus flows naturally onto the network. If an export arrangement has been made with an energy supplier, this has some value. However, the underlying value of each kWh exported is based on wholesale electricity prices, which are roughly half of the retail price, as they do not include network and other charges. This and the transaction costs that the utility incurs for measuring and settling export make it preferable to displace import rather than sell export. No such problems are attached to heat only technologies; the reason that solar thermal systems displacing electric immersion water heating (which can be stored for later use) can paradoxically have a higher value than electricity production from a PV system which cannot be economically stored.

Most micro CHP products under consideration today are fossil fuel fired and although they offer a highly cost effective carbon mitigation solution under current conditions, they will become less effective as fuel prices increase and the carbon intensity of grid electricity decreases. Such technologies thus have a window of opportunity of perhaps 20-30 years before alternatives such as heat pumps using low carbon electricity become more appropriate for domestic applications. There will however remain a niche opportunity for solid biomass micro CHP; already one or two products are under development. Liquid biofuels are unlikely to be available to the domestic heating sector due to limited fuel availability and the more pressing demands of the transport sector.

We shall now consider the characteristics and role for each Microgeneration technology.

Solar PV (Photovoltaic)

The majority of commercially available PV products are based on crystalline silicon which produces a flow of electrons when struck by solar radiation. This DC power requires power electronics to convert it to 230 volt AC suitable for use in the home. The embodied energy in the production of the silicon cells and the ancillary components is significant; indeed, the electricity produced by a typical UK PV system over its entire life, results in CO_2 emissions of between 0.22kg/kWh[13] and 0.25kg/kWh[14], admittedly only half of the displaced grid mix, but not zero carbon by any stretch of the imagination and not particularly impressive when compared with other Microgeneration technologies.

What is more, the cost of a typical 2kWp PV system, which will deliver around 1600kWh per annum, is in the region of £10,000 without subsidies. Even with credit from ROC (Renewable Obligation Certificates) and assuming exported power has a relatively high value, the paybacks are approaching 100 years.

So why has so much attention (and tax payers money) been focussed on PV?

Protagonists would argue that the cost will fall over time (if we invest enough to stimulate the market) and that the embodied CO_2 will also fall as new production techniques are developed; that does not answer the question of why we are still funding what is clearly a sub-optimal technology today. If the new technologies such as thin film and dye-sensitised materials do show promise, surely we should be focussing our efforts and investment in bringing those to market, rather than subsidising yesterday's technology. Otherwise the cost reductions so far demonstrated are not convincing; the cost of PV would have to fall by a factor of 10 to compete with micro CHP and nobody is claiming that.

Other arguments are that building-integrated PV can displace the cost of conventional roofing materials and that, as a prestige cladding material, it is cheaper than polished granite, but that does still not address the central argument that PV is not a cost effective carbon mitigation solution and that there are better ways of investing our finite resources.

Micro wind

Micro wind turbines can be either mounted on buildings or free-standing and can be either vertical axis (VAWT) or horizontal axis (HAWT). Generally speaking buildings mounted units are cheaper to install as they require no tower, but are more susceptible to the turbulent wind conditions found near buildings which will significantly reduce their output.

VAWT are less influenced by turbulent wind conditions, but tend to be rather larger and considerably more expensive for the same nominal power output, although their actual generation over the course of a year may be higher for the same rated output as a HAWT.

Larger HAWT from 5kWe upwards are usually located away from buildings or other obstructions and have demonstrated effective performance. However, there are limited applications for such products which represent a significant investment, around £18,000 for a 5kWe unit generating electricity worth typically £1350 per year.

The EST study identified micro wind products at the 1kWe level as a major component of their 2050 target for Microgeneration, so when the Windsave 1kWe product was launched by B&Q last year, it seemed that this was a technology whose time had come. However, there are many who are concerned that such products may not deliver the electricity production levels expected for a number of technical reasons, even in locations with theoretically favourable wind conditions.

There is clearly a need to test these micro wind devices in real applications to demonstrate the potential benefits, and the EST has recently initiated a trial of micro wind devices to this end. However, if we assume that they do in fact perform as claimed by the manufacturers, micro wind can deliver CO_2 savings far more cost effectively than PV for example.

Solar thermal

Solar thermal systems use either a series of evacuated tubes or glazed panels to capture solar radiation and heat hot water. Some evacuated tubes use an intermediate heat exchange medium, but the overall principle is the same. The hot water is then pumped through the lower of two heat exchanger coils in a hot water cylinder to provide domestic hot water; a second coil located above this one is normally connected to the primary heating system to raise the temperature in the cylinder to a suitable level when solar heating alone is insufficient. Typically such systems provide around 50% of a household's needs over the course of a year and can cost between £2-4000. Unlike solar PV which generates valuable electricity, solar thermal generates heat which, depending on the primary fuel being displaced is worth significantly less, generally between £50-150 per year. Likewise the carbon mitigation value is also substantially lower unless the primary fuel is electricity.

Despite the rather poor economic case, solar thermal is the most popular Microgeneration technology in the UK with more than 80,000 systems installed. In other countries with warmer climates the need for frost protection are absent and relatively simple, thermosyphon systems with integrated hot water header tanks are common; these systems are considerably cheaper and, combined with their higher output (due to geographic location) can be a cost effective solution to the provision of hot water.

Heat pumps

There are several different types of heat pumps, but the two main technologies normally considered for Microgeneration are Ground Source (GSHP) and Air Source (ASHP) heat pumps, both of which produce hot water from ambient sources.

Heat pumps are essentially fridges in reverse, comprising three main components:

1 The evaporator, which extracts heat from its surroundings by evaporating a refrigerant,
2 A condenser which gives off heat to its surroundings as the refrigerant condenses,
3 A compressor which pumps the refrigerant through the evaporator and compressor.

In a GSHP the evaporator is connected to a pipe which is buried in the ground and extracts heat from it. The pipe can either be installed down a vertical borehole 30-100 metres deep, or horizontally in a shallow trench (space permitting). The condenser is connected to the central heating circuit in the house, to heat radiators and the water in the hot water cylinder, as in a conventional hydronic (wet) central heating system.

In an ASHP, the evaporator takes the form of a fan coil unit, a significantly cheaper solution providing more flexibility as to location, although they do need to be carefully sited to avoid noise problems; the performance of ASHP is lower than GSHP as their heat source is cooler when most heat is required.

The COP (Coefficient of Performance) - the ratio between electricity in to heat out - is typically between 2.5 to 3.5 over a complete year for ASHP and GSHP respectively. Already today GSHP compares favourably with gas heating in terms of carbon, but is somewhat less economic, due mainly to the high marginal cost, up to £4000 more than a gas boiler. Operating costs are lower for GSHP than gas, but ASHP is higher due to its lower COP. Natural gas today costs around 2.5p/kWh and electricity (standard tariff) around 9p/kWh; thus gas and heat pump systems have similar running costs when the COP is ~3.5. However, if an off peak tariff is used, the COP can be less and still achieve running cost savings; still, when gas is available ASHP cannot compete on economic terms alone. The situation changes substantially, however, where no mains gas is available and the alternatives tend to be LPG, oil or coal; then both capital and operating costs as well as carbon tip in favour of both types of heat pump.

It is interesting to consider the long term role of heat pumps as the carbon mix of the grid falls in line with UK aspirations to reduce carbon by 60% by 2050. This implies a carbon content of 0.18 kg CO_2/kWh, less than the content of natural gas at 0.194kg CO_2/kWh. In this case, even electric resistance heating will have a lower carbon footprint than gas central heating; it is also highly likely that gas will increasingly become a premium fuel and, like biodiesel today, uncompetitive for domestic heating applications.

Heat pumps are a viable investment now, (particularly GSHP with an expected life of 50 years for the ground loop) even though the immediate economics are less attractive than the likely lifetime value.

Biomass

A biomass boiler is installed with a conventional (radiator) central heating system. It burns biomass, usually wood pellets in place of gas, oil or LPG. It is somewhat larger than a gas or oil fired boiler and requires a substantial fuel store. The wood pellet fuel is stored in a bulk container from where a vacuum tube draws the fuel to a small store next to the boiler itself. The boiler then draws the pellets as required to the boiler where it is first heated to produce combustible gas; this is then burned to heat water as in a conventional boiler to provide space and water heating.

As with heat pumps, biomass is only economically viable where there is no natural gas supply, and where a local biomass fuel supply is available. It is an alternative to fuel oil or LPG where no mains gas is available and, like them, requires fuel storage which can be in any dry building near the boiler. The economics depend on the cost of the local fuel supply, but the costs are generally competitive with the other fuels. More importantly, biofuels are less susceptible to the highly volatile price variations in oil and gas prices and should become increasingly competitive.

In environmental terms, biomass (provided the fuel is sourced locally and from a sustainably managed forest) can make a very significant reduction in household CO_2 emissions, typically between 4-10 tonnes depending on the fuel displaced. As wood absorbs carbon during its growth and releases CO_2 when it is burnt, it is considered a “carbon neutral” fuel (if the fuel source is managed sustainably to make sure it can be continuously harvested). However, some CO_2 is also released by processing and transport of the fuel so it is not entirely carbon neutral in practice. Although it is advantageous to source local biomass to minimise the transport emissions, the urban myth that biomass loses its environmental benefits if it has to be transported more than 25km are entirely unfounded; even if shipped to the UK from Siberia, it is still lower carbon content than natural gas.

Micro CHP

A micro CHP unit replaces the gas boiler in a conventional central heating system. Current products are floor mounted, typically located in a utility room under a worktop; they are the same size as a standard washing machine. It is expected that wall-mounted products will soon become available as well as a range of products to meet the needs of various other market sectors.

Current micro CHP products are engine driven, either ICE (internal Combustion Engine) or Stirling engines. In both cases gas is used to fuel the engine which drives a generator, the waste heat from which is used to heat the primary central heating circuit. They thus heat the home in the same way as a gas boiler, but also generate electricity, most of which is used in the home; any excess is exported to the network and sold back to the supplier.

A typical micro CHP unit costs around £600 more than a boiler, but offers economic and environmental benefits to the householder. An average home with annual thermal demand of 18,000kWh will generate around 3000kWh of electricity; around 2000kWh will be consumed in the home, with 1000kWh exported to the network. This electricity is typically worth around £150-200, depending on how much is consumed by the householder and how much is sold back to the supplier and at what price. Although it consumes slightly more gas than a modern high efficiency boiler, the net saving is still more than £125 for a family home. In this example, the unit will therefore pay for itself in around 4 years. However, as most commentators have noted, the target market for micro CHP is not the average home, but the homes with *at least* the average consumption, hence the 12 million homes in the target market out of the UK total of 24 million homes.

For the average home, carbon savings of 1 tonne CO_2 per year can be achieved; a larger family home could expect to generate 4000kWh or more, providing an economic benefit of up to £300, a carbon saving in excess of 1.5 tonnes annually and a payback of no more than two years.

Comparison of technologies

The following tables show the relative merits of electricity producing Microgeneration technologies both in carbon mitigation terms of the electricity production and in terms of the overall economic impact of installing the respective technology options in a typical family home. (Note that wind has been assumed to perform in line with manufacturers’ claims.)

Technology	Total CO_2 (kg/year)	CO_2 saving (kg/year)	Lifetime £/tonne	kg CO_2/kWh generated
Condensing boiler	8596	-	-	-
Condensing boiler plus PV	8088	509	786	0.25
Condensing boiler plus wind	8342	254	591	0.06
Micro CHP	7515	1081	55	0.23
Micro CHP (15%)	7042	1555	45	0.18
Micro CHP (20%)	6711	1885	42	0.17
Micro CHP (FC)	6075	2521	48	0.28

Table 1: Cost of carbon mitigation with Microgeneration technologies. Total CO_2 is for home with thermal demand of 23,000kWh and electrical demand of 6000kWh per year. The cost per tonne of CO_2 saved shown here does not take into account the alternative cost of building new capacity in the form of, for example, CCGT central plant as was shown in the EWP 2004 figures, resulting in a negative cost for micro CHP.

Technology	Marginal cost	Annual saving	Payback (years)
Condensing boiler plus PV	£8000	£112/£212	40 - 70
Condensing boiler plus wind	£1500	£47/£97	15 – 30
Micro CHP	£600	£151	4
Micro CHP (15%)	£700	£221	3 – 4
Micro CHP (20%)	£800	£267	3
Micro CHP (Fuel Cell)	£1200?	£240	5

Table 2: Economics of Microgeneration technologies. The alternative savings figures depend on whether the value of ROC is recoverable or not; again wind data assumes manufacturers' claimed performance.

Conclusion

Microgeneration can make a significant contribution to the UK's energy needs. However, it is only possible to develop a sensible energy policy including Microgeneration as a component by undertaking an objective evaluation of individual technologies separately rather than as a homogenous category. There is currently reluctance in Government, perhaps rooted in earlier ill-advised policy attempts, to "pick winners". As this paper has shown, there are clear winners, heat pumps for off-gas and eventually on-gas areas, micro CHP as a transitional solution for on-gas areas and biofuel in a substantial niche market.

Lumping winners and losers in the same pot is unhelpful, creates confusion in the minds of policy makers and householders alike and can lead to perverse distortions of the market. For example, the so-called “Merton Rule” which seeks to promote Microgeneration by mandating a percentage of Renewable generation on new developments, distorts the market *against* cost-effective low carbon solutions which are not “renewable”; as we have seen there are some renewable generation technologies which have a higher specific CO_2 content than others based on fossil fuels.

There is a danger that the uncritical advocacy of Microgeneration may lead to the implementation of a sub-optimal energy policy and, worse still, create a backlash against all Microgeneration on the basis of those technologies which not only fail to deliver real benefits, but may even cause nuisance to their owners and those nearby.

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