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Keeping the Lights On

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I would like to thank Lord Lawson and the Global Warming Policy Foundation for inviting me to deliver the annual lecture - an important event in the calendar.

As a member of the Cabinet for four years I supported Coalition energy policy. However I have become increasingly aware from my own constituency and from widespread travel around the UK of intense public dissatisfaction with heavily subsidized renewable technologies in particular onshore wind.

I have used the last three months since leaving the Cabinet to learn more about the consequences of this policy. And what I have unearthed is alarming.

Our current policy will cost £1,300bn up to 2050.[1]

It fails to meet the very emissions targets it is designed to meet.

And it fails to provide the UK's energy requirements.

I will argue that current energy policy is a slave to flawed climate action. It neither reduces emissions sufficiently nor provides the energy we need as a country.

I call for a robust, common sense energy policy that would encourage the market to choose affordable technologies to reduce emissions, and give four examples:

- promotion of indigenous shale gas
- large scale localised Combined Heat and Power (CHP)
- small modular nuclear reactors
- rational demand management

The vital importance of affordable energy

But first, let us consider what is at stake. We now live in an

almost totally computer-dependent world. Without secure power the whole of our modern civilisation collapses: banking, air traffic control, smart phones, refrigerated food, life-saving surgery, entertainment, education, industry and transport.

We are lucky to live in a country where energy has been affordable and reliable.

Yet we cannot take this for granted.

While most public discussion is driven by the immediacy of the looming 2020 EU renewables target; policy is actually dominated by the EU's long-term 2050 target.[2]

The 2050 target is for a reduction in greenhouse gas emissions by 80 percent relative to 1990 levels.
The target has been outlined by the European Commission.[3] But it is only the UK that has made it legally binding through the Climate Change Act - a piece of legislation that I and virtually every other MP voted for.

The 2050 target of cutting emissions by 80 percent, requires the almost complete decarbonisation of the electricity supply in 36 years.[4]

In the short and medium term, costs to consumers will rise dramatically, and the lights would eventually go out. Not because of a temporary shortfall, but because of structural failures, from which we will find it extremely difficult and expensive to recover.

We must act now.

The purpose of my address today is to set out how.

The 2050 Target – what it means in practice

By 2050, the aim is to produce virtually all of our electricity with "zero carbon" emissions.
Yet at the moment over 60 percent of our electricity is produced by carbon-based fossil fuel – mainly gas and coal.[5] And the emissions of this "carbon" portion have to be removed almost completely.

Yet cutting carbon out of electricity production isn't enough. Heating, transport and industry also use carbon based fuels.

In fact, to hit the 80 percent reduction target, we will have to abolish natural gas in most of our homes. No more cooking or central heating using gas. Our homes must become all-electric.[6]

Much of the fuel used for transport will have to be abolished too. 65 percent of private cars will have to be electric.[7]

This is a point that is little understood. The 2050 target commits us to a huge expansion of electricity generation capacity, requiring vast investment.

The EU's suggested route to meet this target – and how it doesn't work

So where does such a supply of zero-carbon electricity come from? The European Commission offers several possibilities, but its particular enthusiasm is for renewable energy, under what it calls its "High RES" (Renewable Energy Sources) scenario.[8] In this scenario, most of the electricity comes from wind power.[9]

This is regrettably entirely unrealistic.

The investment costs of generation alone are prohibitive. They are admitted by the EU to be staggering. The High RES scenario alone would require a cumulative investment, between the years 2011 and 2050, of €3.2 trillion.[10]

Even if you could find such sums from investors, they will require a return and a large premium to de-risk a very hazardous investment. The margins will be astonishing. As Peter Atherton of Liberum argues, the public will not readily accept profits that large for the energy companies.

But if investment is tricky, we only need to consider the scale of construction.

Wind capacity in the EU 27 must rise from 83 GW in 2010 to 984 GW in 2050.[1] It means an increase from 42,000 wind turbines across Europe, to nearly 500,000 wind turbines. This would require a vast acreage of wind turbines that would wall-to-wall carpet Northern Ireland, Wales, Belgium, Holland and Portugal combined.

There, at the heart of the Commission's "high RES" decarbonisation policy, is the fatal flaw. At any practical level, it cannot be achieved. It simply will not happen. Yet, as far as EU policy goes, it is the most promising option, on which considerable development resource has been expended.

UK's plans to meet the targets are no better

Knowing this to be unrealistic, no other country in the European Union apart from the UK has made the 2050 target legally binding.

So having signed up to it, how does the UK hope to deliver all this carbon neutral electricity? The target is, in theory, technology-neutral. The Coalition Government acknowledges shortcomings in wind by making only "significant use" of the UK's wind resources while taking into account ecological and social sensitivities of wind.[11]

[1] See Summary Energy Balance Indicators (B), page 73 of 2050 Roadmap, Impact Assessment: http://ec.europa.eu/energy/energy2020/roadmap/doc/sec_2011_1565_part2.pdf

But if wind doesn't make up the bulk of zero-carbon electricity supply, then that would mean building new nuclear at the rate of 1.2GW a year for the next 36 years. Put simply, that's a new Hinkley Point every three years.

In addition UK policy requires building Carbon Capture and Storage (CCS) plants which take CO2 emissions from gas and coal and buries them in the ground. But these are fuelled by gas or coal at the rate of 1.5GW a year. While nascent, this technology is known to cut efficiency by a third and treble capital cost.

So the British nuclear-led option is no more realistic than the Commission "high RES" scenario or any other of the decarbonisation options. There is simply no plausible scenario by which the British government can conceivably meet its 80 percent emission cut by 2050.

And yet, despite this doomed policy, we provide subsidies for renewables of around £3 billion a year - and rising fast.[12] This is a significant cost burden on our citizens.

In fact it amazes me that our last three energy secretaries, Ed Miliband, Chris Huhne and Ed Davey, have merrily presided over the single most regressive policy we have seen in this country since the Sheriff of Nottingham: the coerced increase of electricity bills for people on low incomes to pay huge subsidies to wealthy landowners and rich investors.

Furthermore the cost is rising, not falling. DECC wrongly assumed that the price of gas would only rise. Four years ago the Energy Secretary confidently argued that renewables would be cheaper than gas by 2020. But this was based on a DECC forecast that gas prices would double.

Instead gas prices have fallen. DECC has revised downwards its forecasts of 2020 gas prices to roughly what they were in 2011 - just 60p a therm.[13] Wind power just isn't competitive with gas. But the drop in gas prices raises the costs of renewable subsidies, already 'capped' at £7.6 billion in 2020, by 20 percent. This is unaffordable.

Climate science

Before I go on to outline an alternative, let me say a few words about climate science and the urgency of emissions reduction.

I readily accept the main points of the greenhouse theory. Other things being equal, carbon dioxide emissions will produce some warming. The question always has been: how much? On that there is considerable uncertainty.

For, I also accept the unambiguous failure of the atmosphere to warm anything like as fast as predicted by the vast majority of climate models over the past 35 years, when measured by both satellites and surface thermometers. And indeed the failure of the atmosphere to warm at all over the past 18 years - according to some sources. Many policymakers have still to catch up with the facts.
I also note that the forecast effects of climate change have been consistently and widely exaggerated thus far.

The stopping of the Gulf Stream, the worsening of hurricanes, the retreat of Antarctic sea ice, the increase of malaria, the claim by UNEP that we would see 50m climate refugees before now – these were all predictions that proved wrong.

For example the Aldabra Banded Snail which one of the Royal Society's journals pronounced extinct in 2007 has recently reappeared, yet the editors are still refusing to retract the original paper.[14]

It is exactly this sort of episode that risks inflicting real harm on the reputation and academic integrity of the science.

Despite all this, I remain open-minded to the possibility that climate change may one day turn dangerous. So, it would be good to cut emissions, as long as we do not cause great suffering now for those on low incomes, or damage today's environment.

The inadequacies of renewable energy to meet demand

Let me briefly go through all the renewable energy options and set out why they cannot supply the zero-carbon electricity needed to keep the lights on in 2050.

Onshore wind is already at maximum capacity as far as available subsidy is concerned. Ed Davey recently confirmed, if current approval trends in the planning system continue, the UK is likely to have 15.25 GW of onshore wind by 2020. This is higher than the upper limit of 13 GW intended by DECC.

This confirms what the Renewable Energy Foundation has been pointing out for some time – that DECC is struggling to control this subsidy drunk industry. Planning approval for renewables overall, including onshore wind, needs to come to a halt or massively over-run the subsidy limits set by the Treasury's Levy Control Framework.

However, this paltry supply of onshore wind, nowhere near enough to hit the 2050 target, has devastated landscapes, blighted views, divided communities, killed eagles, carpeted the countryside and the very wilderness that the "green blob" claims to love, with new access tracks cut deep into peat, boosted production of carbon-intensive cement, and driven up fuel poverty, while richly rewarding landowners.

Offshore wind is proving a failure. Its gigantic costs, requiring more than double the subsidy of onshore wind, are failing to come down as expected, operators are demanding higher prices, and its reliability is disappointing, so projects are being cancelled as too risky in spite of the huge subsidies intended to make them attractive. There is a reason we are the world leader in this technology – no other country is quite so foolish as to plough so much public money into it.

Hydro is maxed out. There is no opportunity to increase its contribution in this country significantly; the public does not want any more flooded valleys. Small-scale in-stream hydro might work for niche applications - isolated Highland communities for example - but the plausible potential for extra hydro is an irrelevance for the heavy lifting needed to support UK demand for zero-carbon electricity.

Tidal and wave power despite interesting small-scale experiments is still too expensive and impractical. Neither the astronomical prices on offer from the government, nor huge research and development subsidies have lured any commercial investors to step into the water. Even if the engineering problems could be overcome, tidal and wave power, like wind, will not always be there when you need it.

Solar power may one day be a real contributor to global energy in low latitudes and at high altitudes, and in certain niches. But it is a non-starter as a significant supplier to the UK grid today and will remain so for as long as our skies are cloudy and our winter nights long. Delivering only 10 percent of capacity, it's an expensive red herring for this country and today's solar farms are a futile eye-sore, and a waste of land that could be better used for other activities.

Biomass is not zero carbon. It generates more CO_2 per unit of energy even than coal. Even DECC admits that importing wood

pellets from North America to turn into hugely expensive electricity here makes no sense if only because a good proportion of those pellets are coming from whole trees.

The fact that trees can regrow is of little relevance: they take decades to replace the carbon released in their combustion, and then they are supposed to be cut down again. If you want to fix carbon by planting trees, then plant trees! Don't cut them down as well. We are spending ten times as much to cut down North American forests as we are to stop the cutting down of tropical forests.

Meanwhile, more than 90 percent of the renewable heat incentive (RHI) funds are going to biomass. That is to say, we are paying people to stop using gas and burn wood instead. Wood produces twice as much carbon dioxide than gas.

Waste to energy is the one renewable technology we should be investing more in. It is a missed opportunity. We don't do enough anaerobic digestion of sewage; we should be using AD plants to convert into energy more of the annual 15 million tonnes of food waste. But this can only ever provide a small part of the power we need.

So these technologies do not provide enough power. But they also don't cut the emissions. And if you'll bear with me I want to explain why.

Emissions reduction in practice

We know that Britain's dash for wind, though immensely costly, regressive and damaging to the environment, has had very little impact on emissions.

DECC assumes that every MWh of wind replaces a MWh of conventionally generated power.

But we know and they know that this is probably wrong at present, and is all but certain to be wrong in the future, when wind capacities are planned to be much higher.

According to an Irish study, because wind cannot always supply electricity when it is needed, backup from gas and coal power plants are required.[15] When the carbon footprint of wind is added to that of the backup energy generators the impact on the environment is actually greater.

System costs incurred by the grid in managing the electricity system, especially given the remoteness of many wind farms, make it worse still.

And a wind-dominated system affects the investment decisions other generators make.

So the huge investment we have made in wind power, with all the horrendous impacts on our most precious landscapes, have not saved much in the way of carbon dioxide emissions so far. What savings, if any, have been bought at the most astonishing cost per tonne?

Four possibilities – achieving emissions targets, supplying energy

So what is achievable? If we are to get out of the straight jacket of current policy, what can be done? I want to explore four technologies which, combined, would both reduce emissions and keep the supply of power on.

The shale gas opportunity

In contrast to Britain's dash for wind, America's dash for shale gas has had a huge impact on emissions.

Thanks largely to the displacement of coal-fired generation by cheap gas, US emissions in power generation are down to the level they were in the 1990s and in per capita terms to levels last seen in the 1960s. Gas has on average half the emissions of coal.

It has cut US gas prices to one-third of European prices, which means that we risk losing many jobs in chemical and manufacturing industries to our transatlantic competitors. We are sitting on one of the richest shale deposits in the world. Just 10 percent of the Bowland shale gas resource alone could supply all our gas needs for decades and transform the North West economy.[16]

The environmental impact of shale would be far less than wind. For the same output of energy, a wind farm requires many more truck movements, takes up hundreds of times as much land and kills far more birds and bats. Above all, shale gas does not require regressive subsidy. In fact, it would bring energy prices down.

Not only does shale gas have half the emissions of coal; it could increase energy security. Currently 40 percent of the coal we burn in this country comes from Russia.[17] Far better to burn Lancashire shale gas than Putin's coal.

So the first leg of my suggested policy would be an acceleration of shale gas exploitation. As Environment Secretary I did everything I could to speed up approval of shale gas permits having set up a one-stop-shop aiming to issue a standard permit within two weeks. But I was up against the very powerful "green blob" whose sole aim was to stop it.

Combined Heat and Power

But there is another advantage of bringing abundant gas on stream. We could build small, local power stations, close to where people live and work. This would allow us to use not just the electricity generated by the power station, but its heat also.

Combined heat and power, or CHP, cuts emissions, cuts costs and creates jobs.

The generous EU estimate of the current efficiency in conventional power stations is about 50 percent. The best of the CHP plants deliver 92 percent efficiencies.[18]

Yet despite these attributes CHP is treated as the Cinderella to the European Commission's favoured Hi Renewable Energy Strategy.

Renewables – especially wind – have been showered with lucrative guarantees, in the form of doubled or trebled electricity prices – thereby absorbing available investment capital.

Whereas the Commission attributes CHP's failure to the "limited" efficiency and effectiveness of its CHP Directive.[19]

I am a realist. CHP does have high capital cost and limited returns with payback periods longer than normally considered viable. Given the commercial risks, dividends from energy efficiency alone have not been sufficient to drive a large-scale CHP programme.

But the Coalition Government recognise this too in seeking to promote energy efficiency in the NHS.

Its buildings consume over £410 million worth of energy and produce 3.7 million tonnes of CO_2 every year. Energy use contributes 22 percent of the total carbon footprint and, in its own terms, the NHS says that this offers many opportunities for

saving and efficiency, allowing these savings to be directly reinvested into further reductions in carbon emissions and improved patient care.[20] In 2013, therefore, it decided to kick-start its energy saving programme with a £50 million fund, aiming to deliver savings of £13.7 million a year.[21] CHP comprised a substantial part of this spending.[22]

To kick-start a broader national programme, providing state aid or financial incentives would be appropriate, especially as the effect would be more cost-effective than similar amounts spent on renewables.

In the United States, the value of CHP is beginning to be recognised as the most efficient way of capitalising on the shale gas bonanza. One state – Massachusetts – has delivered large electricity savings in recent years through CHP.[23] CHP capacity in the United States is currently 83.3GW compared with about 9GW here.[24]

Actually, between 2005 and 2010, the production of both electricity and heat from CHP installations in the UK fell, a dreadful indictment of the last Labour government's energy policy. The installed capacity of wind increased by over 500 percent, despite a massively inferior cost-benefit ratio.[25]

But I do want to highlight how revolutionary CHP technology can be in affording the localisation of the electricity supply system. Transmission losses, can account for 5-7 percent of national electricity production. A 20 percent reduction in transmission loss would be the equivalent of saving the output of another large nuclear installation.[26] This is why CHP can deliver efficiency ratings of up to 90 percent: the system heat is produced where it can be used.

For instance, Leeds Teaching Hospital and the University of Leeds together have financed their own dedicated power station,

comprising CHP units and an electricity generation capacity of 15MW.[27]

With this model, it is easy to imagine office buildings, supermarkets and other installations operating CHP units of 1.5MW or less.

In fact, results from Massachusetts shows that 40 percent of total energy supply could be CHP. Freiburg in Germany is already producing 50% of its energy from CHP up from 3% in 1993.

Implemented nationally, this revolutionary programme of localised electricity production would massively increase the resilience of the system, considerably improve energy efficiency overall, and ease pressure on the distribution system. In total, we would save the equivalent of 9 Hinkley C's.

Small modular nuclear

The third technology is an innovative approach with small nuclear reactors integrated with CHP.

Our policy has consistently favoured huge nuclear and coal plants, remote from their customers. Given that 40 percent or more of the total energy production from a nuclear plant is waste heat, such plants are ostensibly ideal for CHP, but there is no economic way of using the waste heat.
I think there is a further massive obstacle to achieving 40 GW capacity from large nuclear plants; there are simply not enough suitable sites and not enough time to build them.

Small nuclear plants have been running successfully in the UK for the last thirty years. Nine have been working on and off without incident and the technology is proven.

Factory built units at the rate of one a month could add to the capacity at a rate of 1.8 GW per year according to recent select committee evidence from Rolls-Royce. [28]

Small factory built nuclear plants, could be located closer, say within 20 to 40 miles, to users and provide a CHP function.[29] Installed near urban areas, they can deliver electricity and power district heating schemes or, in industrial areas, provide a combination of electricity and process heat.[30]

I welcome the Government's feasibility study into this technology. What is holding up full commercial exploitation is the cost of regulatory approval, which is little different from a large-scale reactor.

I also note that the US Department of Energy has commissioned the installation of three different modular reactors at its Savannah River test facility, with a view to undertaking generic or "fleet" licensing.[31] We should learn from them as a key priority.

Demand management

The fourth leg of my proposal is demand management. The government is tentatively investigating smart meters and using our electric cars as a form of energy storage for the grid as a whole.[32] That is to say, in the future, on cold, windless nights, people might wake to find that their electric cars have been automatically drained of juice to keep their electric central heating on. This is crazy stuff!

It is both impractical and yet not nearly bold enough. Dynamic demand would be a better policy for demand management that would also be cheaper.

It requires the fitting of certain domestic appliances, such as refrigerators, with low-cost sensors coupled to automated

controls. These measure the frequency of the current supplied and switch off their appliances when the system load temporarily exceeds supply, causing the current frequency to drop.[33]

Since appliances such as refrigerators do not run continuously, switching them off for short periods of 20 to 30 minutes is unlikely to be noticed and will have no harmful effects on the contents. Yet the cumulative effect on the generating system of millions of refrigerators simultaneously switching themselves off is dramatic – as much as 1.2GW, the equivalent of a large nuclear plant.[34]

In addition, we can imagine a future in which supermarkets' chillers switch off, and hospitals' emergency generators switch on, when demand is high, thus shaving the peaks off demand. We have started this and we need to do much more.

For this reason, I think the Short Term Operational Reserve (STOR), a somewhat notorious scheme whereby costly diesel generators are kept on stand-by in case the wind drops, is not as foolish as it sounds. It would be even more useful in a system without wind power. At the moment it has to cope with unpredictable variation in supply as well as demand.

With as much as a 25GW variation during a day and with a winter peak load approaching 60GW, significant capacity has to be built and maintained purely to meet short-duration peaks in demand. The use and extension of STOR and like facilities can make a significant contribution to reducing the need for peak generation plants.

According to one aggregator, removing 5-15 percent of peak demand is realistic, as part of the new capacity market.[35] This could be worth up to 9GW, effectively the output of seven major nuclear plants, or their equivalent which would otherwise have to be built. As it stands Ofgem has already estimated that

demand management could save the UK £800 million annually on transmission costs and £226 million on peak generation capacity.[36]

Four pillars of energy policy

And there you have it. Four possible common sense policies: shale gas, combined heat and power, small modular nuclear reactors and demand management. That would reduce emissions rapidly, without risking power cuts, and would be affordable.

In the longer term, there are other possibilities. Thorium as a nuclear fuel, sub-critical, molten-salt reactors, geothermal plants connected to CHP systems, fuel made in deserts using solar power, perhaps even fusion one day – all these are possible in the second half of the century.

But in the short term, we have to be realistic and admit that solar, wind and wave are not going to make a significant contribution while biomass does not help at all.

What I have wanted to demonstrate to you this evening, is that it is possible to reduce emissions, while providing power.

But what is stopping this program? Simply, the 2050 legally binding targets enshrined in the Climate Change Act.

The 80 percent decarbonisation strategy, cannot be achieved: it is an all-or-nothing strategy which does not leave any openings for alternatives.

It requires very specific technology, such as supposedly "zero carbon" windfarms, and electric vehicles. Even interim solutions can never be "zero carbon", so these too must be replaced well before 2050.

In guzzling up available subsidies and capital investment "zero carbon" technology blocks the development of more modest but feasible and affordable low carbon options.

Thus, in pursuing the current decarbonisation route, we end up with the worst of all possible worlds. When there is a shortfall in electricity production, emergency measures will have to be taken - what in Whitehall is known as “distressed policy correction”. Bluntly, building gas or even coal in a screaming hurry. The UK ends up worse off than if it adopted less ambitious but achievable targets. Reining in unrealistic green ambitions allows us to become more "green" than the Greens.

We are the only country to have legally bound ourselves to the 2050 targets – and certainly the only one to bind ourselves to a doomed policy.

In the absence of a legally binding international agreement, which looks unlikely given disagreement within EU member states and the position of the BRIC countries, the Climate Change Act should be effectively suspended and eventually repealed. Clause 2 of the Climate Change Act 2008 enables the Secretary of State by order to amend, subject to affirmative resolution procedure, the 2050 target which could have the immediate effect of suspending it.

Then, energy efficiency becomes a realistic and viable option. Investment in energy efficiency, including the Government’s very welcome initiatives on insulation, offers considerable advantages over wind energy. It does not raise overall electricity costs, and may even cut them because the investment costs are matched by the financial savings delivered.[37]

The moral case for abandoning the 2050 targets

We have to remember too that the people who suffer most from a lack of decent energy are the poor.

I have already mentioned that we are redistributing from those with low incomes to wealthy landowners through generous subsidies collected in high energy bills.
The sight of rich western film stars effectively telling Africa's poor that they should not have fossil fuels, but should continue to die at the rate of millions each year from the smoke of wood fires in their homes, frankly disgusts me. The WHO estimates that 4.3 million lose their lives every year through indoor air pollution.[38]

The sight of western governments subsidizing the growing of biofuels in the mistaken belief that this cuts emissions, and in the full knowledge that it drives up food prices, encourages deforestation and tips people into hunger, leaves me amazed.

The lack of affordable and reliable electricity, transport and shelter to help protect the poor from cyclones, droughts and diseases, is a far greater threat to them than the small risk that those weather systems might one day turn a bit more dangerous.

Growth is the solution, not the problem

Among most of those who marched against climate change last month, together with many religious leaders, far too many academics and a great many young people, the myth has taken hold that growth and prosperity are the problem, and that the only way to save the planet is to turn our backs on progress.

They could not be more wrong. The latest Intergovernmental Panel on Climate Change assessment report states that the scenario with the most growth is the one with the least warming. The scenario with the most warming is one with very slow economic growth.

Why?

Because growth means invention and innovation and it is new ideas, new technology that generates solutions to our problems. The IPCC's RCP2.6 scenario projects that per capita GDP will be 16 times as high as today by the end of the century, while emissions will have stabilized and temperature will have stopped rising well before hitting dangerous levels.[39]

The history of the last century shows that dramatic technical breakthroughs are possible where incentives are intelligently aligned - but it's impossible to know in advance where these will come from. Who predicted thirty years ago that the biggest breakthrough would come from horizontal drilling?

We have some of the finest scientists and universities in the world. A fraction of the money spent on renewables subsidies should go towards research and development and specific, well defined goals with prizes for scientists and companies.

Energy efficiency will develop very rapidly if encouraged to do so, cutting emissions.

A common sense policy climate for climate policy

The fundamental problem with our electricity policy over the last two decades has been that successive governments have attempted to pick winners.

Pet technologies introduce price distortions that destroy investment in the rest of the market, with disastrous consequences.

Even Nigel would admit that the liberalisations he introduced to transform the electricity industry in the consumer interest were

frustrated. Sadly, the policies of the last decade or so, have undone many of his reforms.

But like him, I would reliberalise the markets and allow the hidden hand to reach out for technologies that can in practice reduce emissions.

Conclusion

To summarise, we must challenge the current groupthink and be prepared to stand up to the bullies in the environmental movement and their subsidy-hungry allies.

Paradoxically, I am saying that we may achieve almost as much in the way of emissions reduction, perhaps even more if innovation goes well, using these four technologies or others, and do so much more cheaply, but only if we drop the 2050 target, which is currently being used to drive subsidies towards impractical and expensive technologies.

This is a really positive, optimistic vision that would allow us to reinvigorate the freedom of the science and business communities to explore new technologies. I am absolutely confident that by doing this we can reduce our emissions and keep the lights on.

Endnotes

[1] There is no agreed figure on the total costs of the policy, nor indeed any agreement as to what exactly the policy should comprise. Nevertheless, these sources offer credible estimates: http://www.businessgreen.com/digital_assets/4177/Powerful_Targets.pdf, and https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48072/2290-pathways-to-2050-key-results.pdf
However, the European Commission estimates that the additional investment to achieve decarbonisation (over and above that which would be spent anyway) could run to €304bn a year, between 2011-2050, for the whole of the EU. This equates to UK expenditure of £1.3tn, see: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011SC0288&from=EN. The International Energy Agency estimates global costs at $44bn. Apportioned on the basis of contribution to global GDP, this also equates to £1.3tn for the UK, see:
http://www.iea.org/newsroomandevents/pressreleases/2014/may/name,51005,en.html

[2] The target was "endorsed" by the European Council in Brussels on 29/30 October 2009, as outlined in the Presidency Conclusions. As such, it is a political commitment, but not legally binding on member states. See: https://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/110889.pdf

[3] European Commission, A Roadmap for moving to a competitive low carbon economy in 2050, Brussels, 8 March 2011, COM(2011) 112 final, http://eur-lex.europa.eu/resource.html?uri=cellar:5db26ecc-ba4e-4de2-ae08-dba649109d18.0002.03/DOC_1&format=PDF

[4] See: http://ec.europa.eu/energy/energy2020/roadmap/doc/sec_2011_1565_part2.pdf, and http://www.isi.fraunhofer.de/isi-wAssets/docs/e/de/publikationen/Final_Report_EU-Long-term-scenarios-2050_FINAL.pdf

[5] http://www.ref.org.uk/fuel/tablebyyearshare.php?valdate=2012 and http://www.bbc.co.uk/news/business-24823641

[6] The need to close down the domestic gas distribution network is not specifically set out in Commission or UK documents, but is largely accepted as a natural consequence of decarbonisation. See: www.energynetworks.org/modx/assets/files/gas/futures/Delta-ee_ENA Final Report OCT.pdf.pdf
Homes will either have to go "all electric", or rely on heat networks or heat pumps. Different scenarios offer different mixes.

[7] European Commission, Energy Roadmap 2050, Brussels, 15 December 2011, COM(2011) 885 final, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0885&from=EN

[8] Commission Staff Working Paper, Energy Roadmap 2050 Impact Assessment, http://ec.europa.eu/energy/energy2020/roadmap/doc/sec_2011_1565_part2.pdf

[9] European Commission, Energy Roadmap 2050, *op cit*.

[10] See Fig. 25 in the Energy Roadmap 2050, Impact Assessment, *op cit*.

[11] The UK scenario is detailed here:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42562/216-2050-pathways-analysis-report.pdf

[12] For a broad-ranging review of energy subsidies, see House of Commons Environmental Audit Committee, Energy subsidies, Ninth Report of Session 2013–14, 27 November 2013.
http://www.publications.parliament.uk/pa/cm201314/cmselect/cmenvaud/61/61.pdf

[13] *The Daily Telegraph*, Expensive green energy a 'bad gamble' as ministers slash gas price forecasts, 3 October 2014, http://www.telegraph.co.uk/earth/energy/11137332/Expensive-green-energy-a-bad-gamble-as-ministers-slash-gas-price-forecasts.html

[14] *National Geographic*, 13 September 2014, "Extinct" Snail Found Alive—But for How Long?, http://newswatch.nationalgeographic.com/2014/09/13/snails-extinct-rediscovered-animals-science-seychelles-climate-change/

[15] The Energy Collective, 1 July 2012, Wind Energy CO2 Emissions Reductions are Overstated, http://theenergycollective.com/willem-post/89476/wind-energy-co2-emissions-are-overstated

[16] The British Geological Survey estimates there may be 1,300 trillion cubic feet of shale gas present in the north of England. Drilling companies have previously estimated that they may be able to extract around 10% of this gas - equivalent to around 130 trillion cubic feet. With UK consumption at 3tcf per year, that equates to about 40 years supply. http://www.bbc.co.uk/news/business-23069499

[17] As steam coal – the total (2012) was 44%, see: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/170721/et_article_coal_in_2012.pdf

[18] http://setis.ec.europa.eu/system/files/4.Efficiencyofheatandelectricityproductiontechnologies.pdf

[19] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32004L0008&from=EN

[20] http://www.ruh.nhs.uk/about/annual_report/documents/social_responsibility_report_2009-10.pdf

[21] https://www.gov.uk/government/news/new-nhs-efficiency-schemes-set-to-save-137-million-per-year-on-hospital-energy-bills

[22] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/260921/list_of_successful_schemes_final_for_publication.pdf

[23] http://web.mit.edu/cron/project/EESP-Cambridge/Articles/Program%20design/ACEEE%20-%20January%202013%20-%20Frontiers%20of%20Program%20Design%20copy.pdf

[24] http://www.epa.gov/chp/documents/catalog_chptech_full.pdf

[25] http://en.wikipedia.org/wiki/Energy_in_the_United_Kingdom

[26] European Commission, Action Plan for Energy Efficiency: Realising the Potential, Brussels, 19 October 2006, COM(2006)545 final http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52006DC0545&from=EN

[27] http://www.cogenco.com/uk-energy/ressources/documents/1/44529,Leeds-Tchng-Hosp-NHS-trt-Uni-of-le.pdf

[28] Also commenting was David Clarke, chief executive at the Energy Technologies Institute. He said: "Fundamentally, we see the small module opportunity driven by economics in terms of the potential for low-cost energy and reduced need for cooling water compared with big nuclear plants, meaning that you open up more opportunities for sites on which you can build these units, and then there is potential for siting them closer to centres of population so that you can use the waste heat off-site". http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/energy-and-climate-change-committee/small-nuclear-power/oral/10962.pdf

[29] Icelandic experience is useful here: The Nesjavellir geothermal CHP plant in Iceland services almost the whole of Reykjavik and sends hot at water over 27km. In initial tests, its overall flow rate was around 560 litres per second. Water took seven hours to run the length of the pipe and only cooled by 2ºC. See: http://geoheat.oit.edu/bulletin/bull17-4/art2.pdf The Akranes and Borgarnes district heating service provides the towns of Akranes (6600 inhabitants) and Borgarnes (1950 inhabitants) with geothermal water, as well as some farmhouses, along a 63 km long pipeline. See: http://www.geothermal-energy.org/pdf/IGAstandard/WGC/2010/3418.pdf
Using that as a guide, the SMRs can be 20-40 miles from the districts they serve.

[30] http://www.gen4energy.com/

[31] http://theenergycollective.com/dan-yurman/43216/hyperion-build-small-modular-reactor-savannah-river

[32] *Euractiv*, 29 April 2013, Electric vehicles sell power to the US grid, http://www.euractiv.com/transport/electric-vehicles-sell-electrici-news-519414, and *Autoweek*, 28 April 2013, http://autoweek.com/article/car-news/make-money-your-electric-vehicle

[33] http://www.cired.net/publications/cired2013/pdfs/CIRED2013_0507_final.pdf, and https://pure.strath.ac.uk/portal/files/7103876/dynamicDemand_as_on_IEEE_site_1_.pdf

[34] *The Guardian*, How 'smart fridges' could slash UK CO2 emissions and help renewables, 28 April 2009, http://www.theguardian.com/environment/2009/apr/27/carbon-emissions-smart-fridges-environmentally-friendly-appliances

[35] http://www.kiwipowered.com/pr28.html

[36] https://www.ofgem.gov.uk/ofgem-publications/57026/dsr-150710.pdf

[37] http://ec.europa.eu/energy/efficiency/eed/doc/2011_directive/sec_2011_0779_impact_assessment.pdf

[38] After analysing the risk factors and taking into account revisions in methodology, WHO estimates indoor air pollution was linked to 4.3 million deaths in 2012 in households cooking over coal, wood and biomass stoves. The new estimate is explained by better information about pollution exposures among the estimated 2.9 billion people living in homes using wood, coal or dung as their primary cooking fuel, as well as evidence about air pollution's role in the development of cardiovascular and respiratory diseases, and cancers. http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/

[39] https://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf

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