£300 BILLION

The cost of the Climate Change Act

Peter Lilley MP

With a foreword by Lord Turnbull

The Global Warming Policy Foundation

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Foreword

By Lord Turnbull

No doubt the promoters of the Climate Change Act 2008 are feeling pretty pleased with themselves right now and, in their terms, with some justification.

The 80% reduction in carbon dioxide by 2050 is now firmly embedded in the nation's consciousness (although allowing for a growing economy this means a reduction of around 95% in carbon dioxide per unit of GDP). There is little questioning of this objective in the political realm and in civic society.

The government obediently endorses the Climate Change Committee's recommendations, on the timetable set out in the Act. An international agreement (of sorts) was reached in Paris, with the addition of a suggestion that the increase in the temperature above pre-industrial levels should be capped at even less than 2°C. Ministers have even floated the idea of total decarbonisation.

The fact that the UK is the only country to have set a carbon dioxide reduction target in legislation no doubt gives the promoters a warm glow of righteousness. But are the Act's supporters right to feel so pleased with themselves? Peter Lilley's paper suggests not. He sets out the growing costs to households, the elaborate chicanery in the calculation of the cost figures, and the impact on energy-intensive industries whose output is progressively being relocated abroad so that our carbon consumption continues to rise while we claim our carbon emissions are falling.

He also describes how the renewables regime operates in a way that is extremely regressive, with the better-off – those who own large properties and extensive land – pocketing most of the subsidies paid for by poorer households. Then there is the Act's requirement that the UK government set the carbon budget for 2028–33 by 30 June 2016. The recommendation by the Committee on Climate Change to cut carbon dioxide emissions by 57% by 2030 has been accepted unconditionally by the government. In contrast, the EU has offered an overall reduction of 40% by 2030, but the burden-sharing between member states has yet to be negotiated. The effect of the Act's timetable has been to declare our hand in advance of negotiations, though the effect of Brexit will be that the share-out will need to be renegotiated or delayed until after the UK has left. It is far from certain that the EU offer will translate into legally binding targets at member-state level.

In his party conference speech in 2011 George Osborne said:

> We are not going to save the planet by putting our country out of business. So let's at the very least resolve that we are going to cut our carbon emissions no faster than our fellow countries in Europe.

Whatever happened to that?

In his recent book, *The Fall and Rise of Nuclear Power*, Professor Simon Taylor of Cambridge University describes the Act as a 'doomsday machine'. In combination with the renewables objective so foolishly agreed by Tony Blair in 2007, it requires the government to set more and more ambitious targets for non-fossil fuels, regardless of the cost, and to rigid timetables that take no account of how technologies are developing.

In the short term there is a way out. The CCA states that the Secretary of State can, by order, amend the figures for a carbon budget if it appears to him that 'there have been significant changes affecting the basis on which the previous decision was made'. Since the time when the CCA was being developed, a great deal has changed.

- Temperatures have risen but below the range of most climate change models.
- Many of the predictions about the harmful effects of climate change have been exaggerated.
- Fossil fuel prices which were expected to continue rising to the point where renewables reached 'grid parity' have fallen under the impact of new extraction technologies, thereby raising the costs of the subsidies required.
- No other country has followed us down the extreme unilateralist path.
- Severe damage is being done to our energy-intensive industries, most recently steel.
- Two of the technologies essential to achieve the carbon dioxide target at reasonable cost are struggling (nuclear power) or research has been abandoned, as in the case of carbon capture and storage.

The figure for the Fifth Carbon Budget should have been reduced or projected forward on a standstill basis. Thereafter a major review of the Climate Change Act should be put in place to take account of the changes in the last decade. Objective estimates of the true costs of the Act should be produced.

Andrew Turnbull
December 2016

Lord Turnbull was Permanent Secretary, Environment Department, 1994–98, Permanent Secretary to the Treasury 1998–2002, Cabinet Secretary and Head of the Home Civil Service 2002–05. He is now a crossbench member of the House of Lords.

About the author

Peter Lilley is the MP for Hitchin and Harpenden. He was formerly the Secretary of State for Trade and Industry in the governments of Margaret Thatcher and John Major and also Secretary of State for Social Security. He was one of only three MPs to vote against the passage of the Climate Change Act and is the author of two previous GWPF publications: *What Is Wrong With Stern?* and *The Stern Review Ten Years On*.

Summary and conclusions

1. The costs of the Climate Change Act, which were not discussed at all during its passage through Parliament, are coming home to roost.
2. Those costs – all ultimately borne by households through higher energy bills, increased taxes and a higher cost of living – are already substantial, growing rapidly and hit the most vulnerable hardest.
3. The best way to help 'just about managing' households would be to rein back on these costs.
4. Despite the recent decisions to curtail onshore wind subsidies, solar subsidies and the Green Deal, the total cost of levies, taxes and subsidies to pay for climate policies is set for an 80% increase by 2020, nearly trebling by 2030 and more than quadrupling by 2050.
5. On the basis of figures from the OBR, DECC and the Climate Change Committee (CCC), the average cost of decarbonising electricity to meet Climate Change Act targets was or will be (in 2014 prices):
    - £327 per household in 2014
    - £584 per household in 2020
    - £875 per household in 2030
    - £1390 per household by 2050 – for the impact of the carbon dioxide emissions tax on electricity prices alone.
6. These costs place a cumulative £10,800 burden on each household, between 2014 and 2030. This is money that could be spent on families' own priorities, and in more efficient sectors of the economy. Country-wide, this cost amounts to an extraordinary £319 billion, over three times the annual NHS England budget.
7. The post-coalition ministerial team at DECC[1] woke up to this impact and began to rein back on some costly subsidies, which is welcome, but merely reschedules the timing of costs. Unless they relax the emissions targets they will not reduce the overall costs.
8. This government should be transparent about the costs of transforming the economy to operate virtually without fossil fuels. Yet coalition DECC ministers tried to pretend climate change policy was practically costless and would even make us better off. Rather than try to persuade people that these costs are justified to benefit future generations, they and other supporters of the Act simply prefer to ignore its costs entirely.

9. That position was always incredible but has been totally discredited by figures released by the CCC,[2] which show total public spending on climate change policies via levies and taxes amounted to £6.76 billion in 2014/5 – equivalent to £248 per household. This figure is on a financial year basis and differs in some components from those we have compiled from DECC sources; notably, it excludes carbon taxes. However, it demonstrates that the cost is already substantial.
10. Official figures understate the system costs of intermittent renewables, omit the cost of biofuels in transport fuels, ignore Britain's share of the EU budget (even though 'at least 20% of the entire European Union budget for 2014–2020 will be spent on climate-related projects and policies'[3]), include nothing for DfID (which is likely to amount to at least £25 billion by 2030) and FCO spending on climate and exclude the mounting indirect costs such as lost jobs and output as a result of having rendered British industry less competitive.
11. Coalition DECC ministers' claims that climate policies cost little and would even make households better off involved a number of devices:
    - They only took account of the one third of levies and taxes which fall on household energy bills. But households also pay through an increased cost of living for the two thirds of climate policy costs that raise the cost of energy for industry.
    - They ignored the cost of measures that are financed by general taxation – but ultimately households bear the cost of taxes too.
    - They largely ignored most of the additional costs that intermittent renewables impose on the electricity system – the need for back-up capacity when the wind does not blow or the sun shine; additional 'balancing' capacity including 'spinning reserve' ready at short notice to cope with fluctuations in supply; and the need to extend and strengthen the grid to connect to distant wind farms etc.
    - Having understated several-fold the impact of climate policies on household costs they offset against it the notional energy savings from more efficient appliances, better insulation and so on, giving a wholly spurious positive figure for the impact of climate and energy policies on households. It is a mistake to offset these efficiency savings against climate policy costs because: continuous improvement in energy efficiency would be desirable (and occurs under market pressures) even if there were no carbon dioxide emissions; energy efficiency reduces the cost of energy, which usually boosts energy consumption thus offsetting any savings and, as energy is decarbonised, energy savings become increasingly irrelevant to reducing carbon dioxide emissions.

12. Other apologists for the Climate Change Act do not stoop to these devices to hide its costs but still claim that the cost of decarbonising the economy will be comparatively modest.
13. Such claims merit more sceptical scrutiny than they have received, for two reasons. First, replacing fossil fuels by low-carbon energy is a grandiose project that is unprecedented in peacetime, and lesser mega-projects from the ground nut scheme to nuclear have invariably overrun in time and budget or failed outright. Second, the current cost of producing electricity from all the alternatives to fossil fuels is a multiple of the current electricity price.
14. The bulk of the reduction in UK emissions of carbon dioxide below their 1990 level so far has not been due to a switch to renewables but instead the dash-for-gas, the great recession post 2008, the closure of coal fired power stations (to comply with EU directives to reduce particulate emissions not carbon dioxide), and outsourcing manufacturing to China and elsewhere. Indeed, on the basis of carbon dioxide emitted in producing the goods and services we consume rather than those produced in the UK, our carbon footprint has actually risen despite all the costly efforts so far.
15. Plans to reach the Climate Change Act target of an 80% reduction in carbon dioxide emissions require virtually eliminating emissions from electric power generation, which counts for about one third of current emissions, and converting the bulk of transport and heating, each of which accounts for a further third, to electricity. Most forecasts largely ignore the cost and even feasibility of those conversions; switching heating from gas to electricity and heat pumps plus storage looks particularly problematic. Instead the focus is on decarbonising a much enhanced electricity sector powering most of the economy.
16. Those who claim that the costs of moving to a carbon-dioxide-free power system will be modest predict that the current huge differential between the cost of low-carbon and fossil generation will soon diminish and eventually disappear. They make several arguments:
    - Subsidies on existing wind and solar capacity will end after 15 years. This is true, but a rising carbon dioxide tax on fossil fuels will provide an ongoing subsidy.
    - The cost of low carbon dioxide electricity should not be compared with the current depressed wholesale price of electricity but with the cost of electricity from new thermal plant which would be the alternative. Insofar as new low carbon plant is needed to expand capacity or replace out of date thermal plant, this is a valid point.
    - When calculating the cost of electricity from new thermal plant they do not use current fuel prices but projected fuel prices over the life of the

plant. DECC's forecast in September 2014 was that the oil price (to which gas is linked) would average \$96.40 per barrel in 2015 rising to \$135 by 2035. It is currently little more than \$50 per barrel, having fallen below \$30!

- They also include in the cost of thermal plant a projected carbon tax/price over the life of the plant. Whatever the merits of the case for putting a price on carbon dioxide emissions, this is an increase in cost of energy. It is ludicrous to present it as saving consumers money.
- They argue that deployment of low-carbon technologies will lead to a fall in their costs as they 'mature'. There is no guarantee that this will occur – nuclear costs have risen despite 50 years of deployment. No allowance is made for possible improvements in fossil technologies yet the shale revolution has dramatically cut the cost of oil and gas and there is scope for continued improvement in the efficiency of thermal generators.
- Optimistic projections assume that the levelised cost of some low-carbon electricity will achieve 'grid parity' with thermal. But this ignores the potentially substantial 'system costs' of variable renewables, which reduce the value of variable renewable electricity (VRE) below that from dispatchable alternatives by 30–50%, even at 30% penetration.
- This cost largely arises from the under-usage of dispatchable plant when used in conjunction with VRE. This would make the cost of using high capital intensive plant like nuclear or carbon capture and storage (CCS) in conjunction with variable renewables even more prohibitive.
- Yet the official decarbonisation strategy depends on using nuclear and CCS in conjunction with VRE.
- For technical as well as cost reasons, nuclear is ill-suited to work in conjunction with VRE. So CCS is vital. So far, the feasibility of deploying this technology at scale remains unproven. Attempts in several countries to develop it have been abandoned. And the UK's £1billion offer to fund pilot projects has finally been shelved.
- However, 'meeting the UK's carbon targets without CCS would cost the UK around £30–40 billion more each year…roughly doubling the expected annual costs' according to Carbon Connect.[4] Even the CCC admits[5] that 'Our estimates, and those of others, suggest the cost of meeting the 2050 target would be twice as high without CCS'.[6]

17. In short: hopes of a low-cost transition to low carbon are based on projections of rising fossil fuel prices (contrary to recent experience), aggravated by continually rising tax on carbon dioxide emissions (itself a cost, not a benefit), the presumption that technical advances in renewables will outpace those in fossil fuels (contrary to recent experience), and ignoring the large system costs

of integrating variable renewables, costs that become prohibitive if back-up power comes from CCS and nuclear. Yet, without CCS, the cost of decarbonisation could double.

18. The government should be transparent about the true cost to households and the dramatic transformation of the economy required by climate change policies.

19. Britain could then have a sensible debate about:
    - the most cost-effective ways of achieving the Climate Change Act target.
    - whether the likely benefits expected to flow from meeting that target justify the costs.

20. A sensible debate on the most cost-effective ways of reducing emissions would reveal an unusual consensus among economists that the current bewildering array of targets, subsidies, levies, taxes and permits is not the most cost-effective way to reduce emissions. The total amount of carbon dioxide that major industries can emit each year is rationed by the European system of permits. So when British companies are induced by quotas, subsidies or taxes to make additional savings using high-cost renewables they simply increase the cost of achieving a given reduction while releasing permits to be used by their EU competitors without reducing total emissions at all.

21. The referendum decision also opens up new opportunities for UK climate policy even if we remain committed to the Climate Change Act. Britain need no longer be bound by EU surrogate targets for renewables and so on. These merely increase the cost of achieving the primary Climate Change Act target. So the UK could reduce the cost of achieving that target by resiling from unnecessary subsidary targets and relying on either Emissions Trading Permits (possibly linked to the EU scheme) or a rising carbon tax.

22. It may be that after such a debate the public would be persuaded that the current and likely costs of cutting our carbon dioxide emissions by 80% are worthwhile. But so far the debate has been averted by pretending that the Climate Change Act is virtually costless, that there are not more cost-effective ways of meeting these targets and that the climate risks averted are imminent, not centuries hence.

1 Introduction

The Climate Change Act was passed in 2008 without Parliament giving any consideration to its cost, even though the government's original impact assessment showed the potential costs (borne by British consumers and taxpayers) were nearly twice the maximum benefits (enjoyed mainly by the rest of the world as a result of the UK's contribution to the abatement of global warming).[7] Back then Parliament was able to enjoy a gratifying and immediate sense of righteousness from unilaterally helping to 'save the planet', whereas the costs lay in the distant future. Now those costs are starting to come home to roost. They are substantial. They are set to grow rapidly. And they are borne disproportionately by the less well off, the elderly and the vulnerable.[8] The best way to help 'just about managing' households would be to rein back on these costs.

These costs are far from just economic. The DECC-commissioned Fuel Poverty Review estimated that of the 43,900 excess winter deaths in England and Wales in 2014/15, 'Ten percent…could conservatively be attributed directly to fuel poverty'. To the extent that climate policy increases energy bills, it will add to this toll.

Naturally enough, those responsible for the Climate Change Act (including all the main political parties and most of the chattering classes) have been reluctant to acknowledge those costs, shrink from discussing them and, when obliged to do so, seek to minimize them. The first Coalition Energy Secretary – Chris Huhne – brazenly claimed that the overall impact of climate change policies was actually to reduce household bills. This is a graver distortion of the truth than the dishonesty that landed him in prison. Sadly, his successor – Ed Davey – also put his name to this assertion in the DECC report on the costs of climate change policies:

> Taken together, the impact of all the government's energy and climate change policies mean that household bills are currently around £90, on average, or six per cent, *lower* than if we just sat on our hands and did nothing. By 2020, the average impact is estimated to be broadly similar, around £92, or seven per cent, *lower* than otherwise.[9] [emphasis added]

That was an astonishing claim to make of a policy that involves massive subsidies of costly energy sources. The Climate Change Committee, albeit with no fanfare, published figures showing that government support for roll out of its policies to decarbonize the UK economy reached £6,400 million in 2014/5 with a further £360 million on research and development. That is already a total cost per household of £248. As we shall see, this does not include all the costs of climate change policies – for example the cost of carbon taxes and emissions permits – but does include the cost of energy efficiency measures that are not about the switch to low carbon. These costs are only a start: climate policy costs are set to rise substantially.

We explain more fully in Section 2 how coalition ministers presented a substantial cost to households as a net benefit. In brief: they ignored the two-thirds of the cost of renewable subsidies that fall on energy used by industry even though all business costs are ultimately paid by households. These higher energy costs for business have contributed to the 'cost of living crisis'. They ignored all costs funded from general taxation. They largely ignored even official estimates of the costs imposed on the electricity system by variable renewable electricity: the need for back-up when wind and sun are weak, the cost of balancing unexpected fluctuations in wind and solar, the cost of extending and strengthening the transmission grid to link to distant wind farms. Then, against this already much understated cost of climate policy, they offset the energy savings from more efficient appliances and better insulation even though such savings:

- do not result from switching to low-carbon energy
- will not reduce emissions once electricity is decarbonised
- occur naturally under pressure of competition
- by reducing the cost of using energy may produce an offsetting boost to demand
- could be enjoyed even if there were no climate policy.

Stripping out these devices the underlying average cost per household was £327 in 2014 and will rise to £584 in 2020, almost treble to reach £875 by 2030 and more than quadruple to upwards of £1,390 by 2050.

These figures only cover the cost of decarbonising the power sector. They ignore the incalculable cost of converting nearly the entire car fleet to electric vehicles and most heating to electricity and heat pumps. They exclude less substantial but already significant costs such as the obligation to include a proportion of biofuels in transport fuels; similar policies worldwide have diverted land from food to biofuels, raising food prices and provoking food riots in poor countries.[10] And they exclude indirect costs such as damage to the economy – lost output and jobs – from unilaterally reducing the competitiveness of British energy-using industries. The closure of the Redcar steel works and Tata Steel's announcement of 1200 job losses, which they blamed on 'crippling electricity costs', are the latest symptom of this. Other energy-intensive industries – aluminium, ceramics, paper and bricks – have also been damaged. UK industrial energy costs are among the highest in Europe: 75% higher than Germany and 45% higher than France. Low energy costs from shale have given the US economy an immense boost. Imposing high energy costs on the British economy inflicts corresponding damage.

These cost estimates are based on official figures that incorporate a pessimistic view of the likely cost of fossil fuels and an extremely optimistic view of the huge technical challenges of transforming our energy system by 2050.

DECC's pessimistic assumption that the oil price would go onwards and upwards has already come a cropper as it is now half the level forecast a year ago. However plausible the assumption that resources will become increasingly scarce, the failure of previous forecasts should have given pause for thought. From Jevons' predictions that we would run out of coal, to the Club of Rome's warnings that we would run out of everything, to the famous Simon–Ehrlich bet,[11] all such forecasts have foundered on mankind's creative capacity to find new resources, new methods of unlocking resources and new alternatives. They additionally project that the price placed on carbon dioxide emissions will rise, which will occur as long as governments so wish. But regardless of the reasons for imposing taxes on carbon dioxide emissions (which it is not the purpose of this paper to challenge), they should be recognised as a cost, not treated as a saving.

By contrast, the optimism that largely decarbonising the economy will proceed without problems is breathtaking. It is a hugely ambitious project, unprecedented in peacetime. The history of major government projects – from the ground nuts scheme to nuclear – is not reassuring. More often than not they far overrun in time and budget and grossly underperform. Even at this early stage, the Office for Budget Responsibility revealed this November that despite new measures, the Levy Control Framework (LCF) cost overrun will persist. Renewable subsidies are now set to overrun the LCF, which was introduced to contain costs, by some £1 billion in 2020.[12]

The technical challenge of replacing dispatchable generators, which can produce electricity when required, by variable renewables – wind and solar – which deliver only when wind and sun oblige, may prove daunting. Some dispatchable power will be needed to maintain supply when wind or sun are weak, but the only low-carbon options are nuclear, which is ill-suited technically, and CCS, which is not yet available. Moreover, both are highly capital intensive, which makes them extremely costly to operate only as back-up plant for when intermittent renewables are not generating sufficiently.

The EU is not the primary cause of Britain's high energy prices, which are largely the result of a self-imposed policy. However, Brexit will enable us to review our commitment to the EU's surrogate targets for renewables and so on, which simply make it even more costly to achieve the primary target set by the UK's Climate Change Act.

We need to look at both the likely costs and the risky challenges in a realistic way, rather than through the cloud of messianic idealism that has prevailed so far. Only then can we have a realistic debate about the most cost-effective ways of reducing carbon dioxide emissions and whether it is worthwhile sticking to the Climate Change Act targets.

2 Understating the cost of climate change policies

DECC used four main devices to understate the cost of climate policy to UK households.

Device 1: Ignoring higher energy costs for business

Although Ed Davey wrote about 'the impact of all the government's energy and climate change policies [on] household bills', he was referring only to the direct impact of policies on *household energy* bills. However, two thirds of the costs of climate change levies fall on other household bills because they are levied on energy used by businesses. The higher energy costs for business are passed on to households in increased costs of goods and services that involve energy in their production and distribution. Higher energy costs contribute to what Ed Miliband (who, having enacted the Climate Change Act, was largely responsible for them) used to refer to as the 'cost of living crisis'.

It is at best economic illiteracy and at worst deliberate deception to pretend that there is some entity called 'business' that can pay for two thirds of the cost of subsidizing renewables on our behalf. If there were, or if DECC ministers had really believed that there were, they would have put the entire cost of supporting renewables on 'business', so relieving households of the entire burden of paying for renewables and the carbon tax. When challenged on why he assumed business's increased energy costs were not passed on to households, Ed Davey responded that, since some businesses are owned by foreigners, part of the costs borne in the first instance by business would result in reduced dividends to foreigners.

> Mr Davey: 'I am just making the point that there are global investors in these companies that we are talking about, who are paying, and they are not getting dividends and so on. If you are being purist about this, Mr Lilley – and I know you are a stickler for that – I am sure you will accept that dividends, who pays the levies and so on will potentially be spread over people who are not in this country and not residents of this country.'[13]

This is a breathtakingly unconvincing argument. Davey was clearly not convinced by it himself. If he had genuinely believed that a significant proportion of the cost of subsidizing renewables could be shifted to foreign shareholders he would surely have loaded the entire cost of renewables onto 'business' to save UK households having to shoulder any of the burden. In fact, less than a third of British business is foreign owned; on average companies' operating surplus accounts for a quarter of value added, of which much less than half is remitted as dividends. So at most a few percent of the burden of UK energy levies would be borne by foreign shareholders. That would still leave no case for pretending that British households do not ultimately bear the vast majority of the increase in energy costs of businesses, which simply raise the cost of goods and services that households consume. Moreover, to the limited extent that higher energy costs are borne by businesses exporting abroad or owned by foreigners, that will undermine their competitiveness and their return on investment. If we are to balance our payments and attract foreign investment, we will have to compensate for this in some other way – depreciation of the exchange rate or additional investment incentives – the costs of which will fall on households.

The actual costs of climate change subsidies, taxes and charges are not specifically identified anywhere in the text of the DECC report on the impact of climate change policies on bills.[14] However, a helpful chart does show in small print what it describes as the cost of 'supporting cleaner energy and keeping the lights on'. This comprises:

- the cost of levies on electricity bills to pay for direct subsidies for renewables
- the impact of carbon taxes and permits
- the impact of renewables on depressing wholesale electricity prices
- the cost of the capacity auctions to maintain sufficient capacity to keep the lights on.

It puts these at £63 for the average household electricity bill in 2014, rising to £129 in 2020 and £204 in 2030.[15]

This covers less than the one third of climate policy costs which impact directly on household energy bills. The remaining costs are levied on businesses' energy costs, which are ultimately borne by households through a higher cost of living. So the true cost to the average British household of these levies and taxes is over three times what they pay directly through their energy bills. In fact, according to OBR[16] and DECC figures, the total cost of renewable levies plus the impact of carbon taxes per household was £231 in 2014 and will reach £420 in 2020 and £612 in 2030. As we shall see, this is only part of the true cost.

It should be noted that the cost of taxes and permits on carbon dioxide emissions is not just the revenue they raise. Since carbon taxes fall on gas and coal generation and these are the marginal suppliers that set the general price of electricity; carbon taxes raise the cost of all electricity *pari passu*. DECC calculates the cost of carbon dioxide taxes on this basis. Indeed, the purpose of putting a price on carbon dioxide emissions is to increase the market price of electricity so that more expensive sources of energy will become less uncompetitive.

DECC offset against this the effect renewables can have in depressing the average wholesale price of electricity. The system operator will always meet demand by drawing first on electricity with the lowest operating costs – normally wind and solar. This will depress the wholesale price of electricity when wind and solar are generating. DECC estimates that this results in a savings in average household energy bills of £5 in 2014, £12 in 2020 and £17 in 2030. We have incorporated three times these amounts in the figures above to allow for their (favourable) impact on business costs. In the long run this discount should disappear if, as DECC assumes, average prices eventually adjust to reflect the full cost of electricity generated by gas generators.

As the carbon dioxide price is increased, it reduces the level of direct subsidy needed and eventually will eliminate the need for subsidy entirely. Eventually, taxes on carbon dioxide emissions will become the main cost of implementing climate policy, at least in the power sector. The government's central projection is that they will rise from £15/tCO_2 currently to £21/tCO_2 in 2020, to £76/tCO_2 in 2030, and £216/tCO_2 in 2050. This will then increase the cost of electricity so as to raise the cost of living by £1,390 per household by 2050.[17]

The device of ignoring the impact of increased costs to business leads on its own to an understatement by two thirds of the cost to average households of decarbonizing electricity generation.

Device 2: Omitting costs borne via general taxation

The second major device DECC ministers employed to conceal the true cost to households of climate change policies was to exclude the cost of measures financed by general taxation. DECC figures only include the cost of levies and taxes on household energy bills. But as CCC figures show, in 2014/5 climate measures financed by general taxes amounted to £1,860 million (including £360 million spent on climate related research and development).[18]

It scarcely needs saying that taxes, like all other costs, are ultimately borne by households. So in total these tax measures amount to a further £68 per household.

Assuming that the cost of tax-funded climate programs remains at the same level per household[19] and adding it to that of climate levies and carbon taxes, brings the total cost to £299 per household in 2014, £488 in 2020, and £680 in 2030.

Device 3: Omitting the full system costs of renewables

Not only does DECC ignore two thirds of the cost of subsidies for renewables and all the policies funded from general taxation, it also understates the total costs of switching from fossil fuels to renewables. In particular, what DECC calls the cost of 'supporting renewables and keeping the lights on' does not reflect the full costs that VRE imposes on the electricity generating system.

Integrating VRE, such as wind and solar, imposes costs on the system. This is discussed more fully in Section 4,[20] but in summary, VRE needs to have:

- dispatchable back-up capacity for when wind and sun are absent or weak
- balancing reserves, some of which must be kept 'spinning', ready to cope with the unpredictability of fluctuations in VRE
- extensions to the transmission network to link to distant wind farms.

These and other 'system costs' increase disproportionately as the share of VRE rises.

DECC largely ignores these system costs. The only item specifically included under what DECC calls 'the cost of supporting clean energy and keeping the lights on' is the Gross Cost of the Capacity Auction. Because of the closure of coal-fired stations, capacity to meet peak demand and unplanned outages was running low and VRE cannot supply much 'assured' capacity. So DECC invited offers to provide spare generating capacity. They also invited large electricity users to offer to reduce demand at times of capacity shortage, but the response was disappointing. DECC accepted offers of reserve capacity totaling 49 GW at an annual cost of £1billion;[21] ironically this is primarily to pay old coal-fired power generators to remain on tap.[22] This is equivalent to some £36 per household and is included in the amounts shown in Section 1.

DECC do not attribute to renewables any amounts for extra transmission costs to link to renewables or extra 'system balancing' due to intermittency. Presumably these costs are included in the general costs of electricity.

However, the Climate Change Committee does recognise that 'Further costs are also incurred for integrating and managing low-carbon generation in the grid, for example from higher transmission costs arising from connecting geographically-remote renewable generation, as well as additional costs for backup capacity for intermittent renewables'.[23]

In respect of the transmission network they refer to the £9 billion of additional transmission investment identified by the Electricity Network Strategy Group that is required to support renewable and other power generation investment. Assuming a 6% discount rate and a 40-year annuity period, this equates to annualised costs of around £600 million in 2020.[24,25]

In respect of 'managing intermittency', they say the marginal cost is 0.8p for each additional kilowatt-hour of intermittent generation.[26] If this were all, it would imply a cost of managing intermittency of £290 million in 2014, rising to £640 million in 2020 and £1.4 billion in 2030. However, this is only the *marginal* cost of coping with additional VRE assuming that by 2030 the system has already installed flexibility measures to adapt to variability that involve an annualized cost of £5.0–5.9 billion (of which £2.3–2.8 billion is on transmission and distribution networks).[27] These measures are:

- 16 GW of additional interconnector capacity
- 4 GW of extra storage capacity
- smart grid and metering capable of adjusting demand by up to 15% within the day (which *inter alia* assumes that in 2030 there will be 11 million electrical vehicles capable of recharging at periods of low demand)
- major extension, strengthening and adaptation of the transmission and distribution network.

The Poyry study from which this is taken puts the total cost of coping with 40% renewable penetration by 2030 at £5.7 billion in 2010 prices, which is equivalent to 3.4p/kWh.[28] This does not include the cost of shedding intermittent generation when high potential generation exceeds demand. This is put at about 0.7p/kWh of additional renewables once the 40% penetration has been reached (about £500 million). However, it gives no estimate for the cost of shedding at lower levels of penetration, so we have not included any figure either.

When asked why the Poyry study is cited as the source of their estimates yet the £5 billion or more of investment needed to provide flexibility is largely ignored, CCC said that 'this is a baseline cost and should not all be ascribed to intermittent renewables'.[29] Further correspondence citing the words of the Poyry report showing this £5 billion was additional expenditure required to cope with intermittency elicited the rather unsatisfactory response that 'we published all the supporting analysis and research so that everyone could make their own calculations and form views – as you are doing'.[30] Given that £5 billion is a very significant sum it is rather important to decide whether all, or part, or none of it is to be attributed to intermittency. We have adopted the same interpretation of the Poyry figures as the Grantham Institute;[31] The International Energy Agency also used Poyry figures, apparently in the same way.

So, on the basis of the 'official' estimates by the CCC, DECC should have identified extra system costs to integrate renewables of £740 million in 2014, £2.8 billion in 2020 (see p. 17) and £6 billion in 2030 – equivalent to £27, £96 and £195 per household.

Those would bring total costs to the average household of climate change policies – on the basis of figures published by DECC and commissioned by the CCC – to £327 in 2014, £584 in 2020 and £875 in 2030.

Device 4: Hiding the cost of decarbonizing the economy

Having understated the cost of climate policies several-fold, DECC then offset against this greatly understated figure, not the benefits flowing from reduced carbon dioxide emissions but the savings in energy costs resulting from more energy-efficient appliances, tighter building regulations and home insulation.*

DECC assumes that but for these efficiency improvements the average household would have used more energy, and that the savings are worth £176 in 2014, £276 in 2020 and £251 in 2030.

But the aim of climate policy is to reduce carbon dioxide emissions not to reduce energy consumption. Indeed, the aim is to decarbonise energy so that we can use as much energy as we choose and can afford without adding to greenhouse gas emissions.

The economist Ross McKitrick has shown that it is far more cost-effective for regulators to focus on their central objective – in this case reducing carbon emissions – than to adopt surrogate targets such as reducing energy use.[32] If emissions from power generation are directly controlled – for example by emissions permits – then marginal increases in energy use could only come from non-carbon sources, and the marginal energy savings would simply reduce demand for non-carbon electricity.

* Although home insulation is often presented as a low-cost way of reducing carbon dioxide emissions, the NAO report 'Green Deal and Energy Company Obligation' (April 2016) found these programmes cost £100 per tonne of carbon dioxide saved.

Once fossil fuels are replaced by renewables or nuclear for electricity generation, increasing energy efficiency will be irrelevant to reducing carbon dioxide emissions.

It is, of course, sensible constantly to strive to use energy – like any other factor of production – more efficiently. Improvements in energy efficiency are beneficial regardless of whether energy use gives rise to greenhouse gas emissions. So lumping energy savings in with costs of renewables is hiding apples behind pears.

Most people have an incentive to use energy more efficiently and business has a competitive incentive to supply increasingly energy-efficient products. Indeed, the history of industrial civilization consists of finding and applying ways of using resources – energy in particular – more productively.[33]

Energy consumption in the UK has fallen since the beginning of the century. But how much is due to simple price elasticity of consumption, how much to increased energy efficiencies in products and buildings, which would have happened under normal market pressures, and how much to the impact of product and building regulations, is open to debate.

The extent to which regulations have accelerated this process is far from clear. The EU report on the impact of the EU's products policies, which underlie DECC's estimates of policy-induced efficiency savings, shows, for example, that take-up of more energy-efficient TV models under normal market pressures preceded introduction of the regulatory standards to which it is now attributed.[34]

There is clearly a case for requiring public-sector landlords and arguably private landlords too to provide cost-effective insulation and heating in their properties because tenants are not in a position to do so. And it is reasonable to require manufacturers to display the energy ratings of their appliances so that consumers can make informed choices. But it is less obvious that there is any need for general statutory regulations to set energy-efficiency standards. Where energy-efficient products benefit individuals and firms, consumers can and generally will acquire them anyway.

So we should be suspicious of regulations that claim to make people better off by forcing them to do what they have an interest in doing anyway. A US study showed that many energy-efficiency regulations cannot be justified on the grounds of reducing carbon dioxide emissions:[35] the extra costs to consumers far outweighs the social cost of carbon used by the regulator to cost carbon dioxide emissions. Regulators instead invoke the supposed savings in energy costs to consumers on the implicit assumption that consumers are too irrational to opt for more energy-efficient products themselves. The possibility that consumers prefer products with higher energy consumption because of other features was not considered. A recent article showed that regulations compelling people to use energy-efficient products have often been introduced at the behest of manufacturers who otherwise could not persuade consumers to buy their products.[36] James Dyson has claimed that EU regulations were specifically tailored at the behest of German competitors to allow their vacuum cleaners to be tested with the bags empty (even though their energy use rises substantially as their bags fill) to make their energy efficiency appear comparable with the Dyson bagless vacuum cleaner.[37] Where people are prevented from buying appliances whose superior performance they value more than their higher energy usage, that is a cost, not a benefit.

As it happens, it is widely accepted that, paradoxical though it may seem, improvements in energy efficiency do not reduce energy use correspondingly. They therefore contribute less than expected to decarbonising the economy. The idea that greater efficiency in energy use will not result in reductions in energy use is, to say the least, counterintuitive. It seems self-evident that if we reduce the amount of energy needed to heat a home or to run our appliances this must reduce energy demand. At the micro level – using less energy to heat our home, run our fridge, or power an activity – less does mean less. But at the macro level – the whole economy – less has in the past meant *more*. The Victorian economist William Stanley Jevons first noticed this:

> It is a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth… The reduction of the consumption of coal, per ton of iron, to less than one third of its former amount, was followed, in Scotland, by a tenfold increase in total consumption, between the years 1830 and 1863, not to speak of the indirect effect of cheap iron in accelerating other coal-consuming branches of industry'.

More recently this paradox – that more efficient use of energy may actually increase energy consumption – has been restated as the Kazzoom–Brookes postulates.[38] Essentially, when ways are found to use energy more efficiently, that reduces the effective price of energy. That will increase demand for the now less costly activity and release income to be spent on other things, which will consume energy. For example, more efficient appliances may reduce the amount of energy people need to run their homes. Some of them may decide to use the appliances more frequently or to buy a second fridge or TV. Or they may use their savings to take a foreign trip – increasing their energy footprint. Less well-off people may be enabled to afford to acquire and run these appliances because of their lower running costs.

Some argue that in this respect energy seems to be like human labour.[39] The immediate impact of each improvement in productivity appears to be to render some people unemployed. In practice they find other work to do. Over the long term the effect of successive labour-saving measures has not been to reduce employment but to raise gross domestic product. Likewise, energy-saving measures release energy to be used – if not in this country then elsewhere on the planet – to boost GDP.

Some empirical studies have shown a 'rebound' effect that offsets more than 100% of the initial savings. But a recent study showed that, even where that was the initial result, once the increased capital cost of more efficient appliances was taken into account the 'rebound' effect was little over a quarter.[40]

That of course highlights the fact that increases in efficiency may not be costless. Robert Gross, in a critique of a pioneering assessment by Policy Exchange of the cost of climate change policy, argued that most efficiency changes are 'practically costless'.[41,42]

Clearly it is not possible to have it both ways. If more energy-efficient appliances are more expensive, that needs to be set against the savings achieved and may reduce the rebound effect. Yet if there are no additional costs the rebound effect may be higher.

In short: more efficient use of energy is a good thing; but because of the direct and indirect 'rebound' effects it may not reduce overall energy use nearly as much as anticipated, if at all. Such rebound effects will be smaller if more energy-efficient appliances cost more, but in that case there is less case for requiring people to buy them. In any case it is more efficient to target the level of emissions rather than setting secondary targets for energy efficiency. So energy efficiency will contribute less to reducing carbon emissions than usually assumed; only a shift to low-carbon energy sources can do that. The cost of moving to low-carbon energy should not be concealed behind notional energy savings.

We therefore exclude both DECC's estimates of energy savings and the costs of energy efficiency programs (like ECO and the Green Deal) from our estimates of the cost of climate change policies per household.

So on the basis of government figures and stripping out the four devices coalition ministers used to conceal the true cost, climate policies to decarbonise electricity on average cost each household:

- £327 in 2014
- £584 in 2020
- £875 in 2030
- £1390 in 2050.

Those figures are compiled from official publications. In the next section we draw on evidence from academia, industry, the City and international organisations to consider how realistic the government's figures and ambitions are.

3 Is decarbonisation of the UK economy feasible at little cost?

Other environmentalists, who do not stoop to these rather disreputable presentational devices used by Coalition ministers to pretend a cost is a benefit, nonetheless claim that the cost of decarbonising the UK economy will be modest.

It would be wonderful if this turns out to be true. But meeting the UK's legally binding target to reduce greenhouse gas emissions to 80% below their 1990 level is a grandiose project. It is hard to think of any similar industrial transformation induced by government fiat apart from mobilizing the economy for total war, and that was not achieved without massive cost.[43] The record of grand public projects far less ambitious than this – from the ground nuts scheme to nuclear power – has invariably been of massive cost overruns and delays, if not outright failure.

What would such a transformation involve? Britain's energy consumption is divided between three main sectors: transport, heating (domestic and industrial) and power (electricity). As Table 1 below shows, although electricity is the smallest of the three in terms of energy consumed, each sector produces around one third of carbon dioxide emissions. It is generally assumed that it will be easiest to decarbonise electricity, and that the only practical way to decarbonise heating and transport will be to change them over to electricity. So the government strategy is progressively and entirely to decarbonise electricity generation while substantially expanding electricity generation, with electric vehicles largely replacing the internal combustion engine and electric heating largely replacing gas. Decarbonising the electric power sector is therefore the core of the project.

Table 1: UK energy consumed (2013) and carbon dioxide emissions (2014) by sector

		Transport	**Heating**	**Power**	**Other**
Energy	(TWh)	786	576	314	
	(%)	45	33	18	5
CO_2 emissions	(MtCO2)	155.2	192.7	153.9	n/a
	(%)	31	38	31	

Source: National Grid Future Energy Scenarios Tables 85 and 87.

The National Grid has set out scenarios based on this strategy. We focus on their *Gone Green* scenario, which is the only one that achieves an 80% reduction in carbon dioxide emissions by 2050. It involves an increase in annual electricity production from renewables, new nuclear and CCS from 64 TWh in 2014 to 559 TWh in 2050.

The levelised cost of electricity (LCOE) for different sources of low-carbon electricity is currently as shown in Table 2 below. All are a multiple of the current wholesale price of electricity which is around £43/MWh.†

If the mix of low carbon capacity is that projected in the *Gone Green* scenario (see Table 3) it would appear, at first sight, that the extra low-carbon electricity will require annual subsidies of around £24 billion in 2050.

† LCOE measures the cost of electricity delivered to the grid. It takes into account both capital and operating costs per unit of electricity produced over the lifetime of the plant. It does not take into account the additional costs imposed on other parts of the system by the variability of output from intermittent generators.

Table 2: Cost of new low-carbon versus new conventional power

	Levelised cost £/MWh
Onshore wind	84
Offshore wind	122
Nuclear	95
Gas CCGT	54
Coal IGCC	63
Current wholesale electricity price	43

Assuming constant fuel prices (gas 43p/therm, coal £32.3/ton) and unchanged carbon price (£15.4/tonCO_2). Source: Jefferies International.

The annual subsidy required to finance the low-carbon energy is supposed to be contained within the LCF. The Treasury set the LCF for 2020 at £7.6 billion (at 2011/12 prices) to fund the roughly 110 TWh of renewables planned for 2020. Revised (as of November 2016) OBR forecasts reveal a £1 billion overshoot in 2020/21, when it is expected to reach the equivalent of £8.6 billion (again in 2011/12 prices),[44] equivalent to £10.7 billion in nominal terms. Yet by 2030 when renewables, CCS and new nuclear are expected to provide three times as much low-carbon electricity, DECC forecasts the subsidy rising to only £11.6 billion. The CCC, even more optimistically, puts the 2030 figure at just £10 billion.

How do DECC, the CCC and others arrive at such relatively low figures?

1. They assume that in 2030 most of the capacity subsidised by Renewables Obligation Certificates will be over 15 years old, and will no longer be eligible forsubsidies. However, two thirds of the renewables in 2030 will have been added since 2020. So in 2030 there will be more than twice the capacity liable to subsidy that there was in 2020. Moreover, old renewables and old nuclear will continue to be effectively subsidized by the carbon tax on fossil power. (When the Carbon Floor Price was introduced this gave a windfall benefit to old nuclear and renewables subsidized by ROCs. The Treasury estimated this at between £1.9 billion and £5.2 billion cumulatively between 2013 and 2020.)[45]
2. They assume that the alternative to producing low-carbon electricity at the high levelised costs shown in Table 2 will not be electricity at the current wholesale electricity price. The price would have to increase sooner or later to cover the replacement cost of thermal plant. That is a not an unreasonable assumption, although if it were not for the policy of closing thermal plant before the end of its natural life the present depressed level of wholesale prices might continue for considerably longer. However, they do not use the LCOE from combined-cycle gas generation, which is about £54/MWh at present fuel prices.

Table 3: Electricity consumption by source: *Gone Green* scenario

	2014/15 TWh	**2020/21** TWh	**2030/31** TWh	**2050** TWh
Nuclear	61.3	57.7	72.7	274.7
Coal	103.7	25.5	0.0	0.0
Coal CCS	0.0	0.0	11.4	11.2
Gas	67.4	40.3	28.8	1.0
Gas CCS	0.0	0.0	7.3	35.0
Gas CHP + CHP Other	20.6	22.1	22.6	0.8
Gas CHP CCS	0.0	0.0	0.0	15.1
Onshore wind	17.5	30.1	44.4	60.8
Offshore wind	15.3	31.4	97.4	110.4
Solar	4.6	13.3	22.5	21.9
Renewable other + RenCHP	26.6	39.6	45.4	29.6
Interconnectors	22.8	72.1	54.4	2.4
Conventional other	6.8	6.7	9.9	0.0
Total	346.6	338.8	416.9	562.9
Of which:				
Renewables, CCS and new nuclear	64.0	114.4	243.4	558.7
VRE penetration	10.8%	22.1%	39.4%	34.3%

Source: National Grid: *Future Energy Scenarios* 2015, Figs 57 and 88.

Instead they project the price of gas and carbon taxes over the life of the plant, which gives a levelised cost of £77/MWh. The subsidy required will therefore be equal to the difference between the levelised cost of each technology and the levelised cost of thermal plant needed to provide the same output.

3. They assume gas prices will rise progressively, increasing the cost of thermal power, which sets the wholesale electricity price in the long term. The gas price tends to follow the oil price with a lag. In September 2014 DECC projected the oil price this year would be $96 per barrel rising to $135 by 2035.[46] It is currently around $45. No-one can predict with any certainty the future path of oil or gas prices. But if the shale gas revolution spreads beyond North America it may well reduce the price of gas relative to oil. So it is extraordinarily unwise to bet the economy on the assumption that oil and gas prices will inevitably recover to the levels needed to justify investing in high-cost renewables.
4. In addition to the projected rise in hydrocarbon prices, DECC factors in a rising carbon price. DECC's central projection is that it will rise from £21/tonne CO_2 in 2020 to £76/tonne in 2030 and £216/tonne in 2050.[47] The higher the carbon

price, the lower the subsidy needed to make low-carbon energy competitive. But it does so by making energy as a whole more expensive. So, whatever the arguments for imposing a carbon price, it is ludicrous to present it as saving consumers money.

5. They assume that investment in renewables and other low-carbon technologies will automatically bring down their costs.

    - They tacitly assume that conventional energy sources will not enjoy any cost reductions from technological advances. In fact the shale gas revolution has produced far greater savings than have been achieved by renewables technologies and in a far shorter time. And contrary to expectations the fall in oil and gas prices has stimulated a further round of cost-cutting advances in that technology. There is also scope for further improvements in the efficiency of gas generators, which will not only reduce costs but cut emissions of carbon dioxide *pari-passu*.
    - Recent reductions in the cost of wind, which have been claimed as evidence of investment leading to cost reductions, can in fact largely be explained by appreciation of Sterling against the Euro (which has reversed since 2015).[48]
    - The rise in nuclear costs, despite more than half a century of experience of building nuclear plants, shows that 'maturity' of a technology does not automatically result in cost savings. Although nuclear was initially hailed as ushering in energy that would be 'too cheap to meter', the planned Hinckley Point C station looks set to be the most expensive nuclear plant ever commissioned. It looks unlikely to be competitive with gas unless the oil price rises to $250 per barrel![49]
    - As the best sites (both in respect of wind and access to the grid) are used up, new wind turbines will have to be located in less good or more expensive locations, thus to some extent offsetting any technological advances.
    - Although solar (photo-voltaic) panels have seen substantial reductions in price, the panels themselves are only around a half of the total cost.[50] So even if the cost of panels fell to zero, that would only halve the cost of solar installations. And as explained below, the value of electricity from solar is particularly low because the sun tends to shine when daily demand is low but tends not to be available at daily and seasonal peaks in demand. So solar is unlikely to be competitive in the UK if its full costs are taken into account (unless very low-cost storage becomes available, which is unlikely in the foreseeable future).

But hopes that renewables will be competitive do not just depend on rising fuel costs and carbon taxes rising and technology costs falling as projected. The whole strategy also depends on two interlinked and hugely optimistic assumptions. The first is that integrating large amounts of variable renewable electricity – wind and solar – will be technically feasible at modest cost. The second is that CCS will be available, at a non-prohibitive cost, to enable the continued use of some thermal plant to balance the fluctuations in VRE.

4 System costs of variable renewable electricity

Electricity is an homogeneous good. EoN's electrons are identical to EDF's electrons – indeed they are all mixed together in the same transmission network. So it is often assumed that all electricity has the same value whether produced from conventional or renewable plants. That in turn leads to the assumption that the competitiveness of different sources of electricity is measured by the plant costs of delivering electricity to the grid (the levelised cost).[51]

However, in addition to the plant costs, it is important to take account of the change in the costs of running the whole system required to integrate new generating capacity into the system. The system needs:

- transmission and distribution lines
- adequate capacity to meet peak demand and occasional plant failure
- 'balancing reserves', some of it 'spinning' ready to meet short-term fluctuations in demand; supply and demand must match every minute since any shortfall leads to a drop of frequency, which can be catastrophic for some users' electrical equipment
- an appropriate mix of generating plants: baseload plants to operate more or less continuously, load-following plants to ramp up and down with the daily and seasonal rise and fall of demand, and peakload plants to come on stream just at peak times.

Even integrating a conventional plant will impose costs or provide benefits depending on its consequences for capacity adequacy, how well it fits in with the mix of different plants needed to cope with the predictable pattern of demand and for its ability to help balance unpredictable fluctuations in demand. But the impact of integrating variable renewable plant is likely to be much more significant, for several reasons:

- wind sites are often far from areas where electricity is consumed so the transmission network may need extending and strengthening
- small solar sites may feed in to the distribution network, which may need to be adapted to transmit the surplus
- unpredictable short-term fluctuations in wind and solar may accentuate the need for short term balancing reserve.

But above all, because VRE produces electricity when wind and sun decree rather than when it is needed, the rest of the system will have to cope with larger and more frequent swings in net demand.

The size of the system costs to integrate VRE will depend not just on the amount and nature of the renewable plant but on the profile of demand and the composition of the existing fleet of generators. Moreover, it may be possible to reduce the system cost over time by altering the mix of generation as old plants are phased out or by introducing other sources of flexibility to offset the variability of VRE. Consequently, it is difficult even to define precisely the system costs of integrating VRE, let alone measure them accurately.

Ideally, any assessment of the additional costs imposed by renewables requires a 'whole system analysis'. This involves comparing the overall system costs for a given pattern of generators and given profile of demand with and without any proposed level of renewables and with or without any new complementary capacity that will provide flexibility. This is too complex in practice for anyone other than the system operator to undertake. Colin Gibson, formerly Power Networks Director at National Grid, has long urged the National Grid and DECC to carry such an assessment out.[52] It is welcome that DECC has recently issued a tender for a whole-system analysis, a study that is expected to take five months. In its absence, such estimates of system costs of VRE as exist have inevitably been ad hoc and have varied widely.

Because of these complexities, many estimates of the cost of renewables either ignore or downplay the system costs, especially those from organisations that are institutionally committed to promoting renewables. That was the approach of coalition DECC ministers and the CCC, although both organisations are now reviewing their past assessments of the system costs of VRE.

The House of Lords inquiry into the resilience of the electricity system was frank about the difficulty of unravelling the issue.[53]

> The extent of costs of maintaining resilience as the reliance on intermittent renewables increases was vigorously debated during our inquiry. We found that it was difficult to understand the different methodologies used, compare figures and reach firm conclusions.

The Lords Committee heard from experts whose estimates ranged widely:

- The CCC suggested 1p/kWh, equivalent to £700 million per annum at 20% penetration and not including extra transmission costs
- Professor Richard Green put system costs at £2.5 billion per annum (2008 prices), of which £1.2 billion was for transmission, by 2020[54]
- Sir Donald Miller, former Chairman of Scottish Power, and Colin Gibson, who put the figure at £5 billion.[55]

The Committee did not refer to the major study by the OECD/NEA of system costs in six countries.[56] The figures for the UK, which are based on data provided by the UK government, are shown in the table below.

Table 4: UK grid-level system costs ($/MWh of renewable electricity)

	Nuclear		Coal		Gas		Onshore		Offshore		Solar	
	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%	10%	30%
Back-up costs (adequacy)	0.00	0.00	0.06	0.06	0.00	0.00	4.05	6.92	4.05	6.92	26.08	26.82
Balancing costs	0.88	0.53	0.00	0.00	0.00	0.00	7.63	14.15	7.63	14.15	7.63	14.15
Grid connection	2.23	2.23	1.27	1.27	0.56	0.56	3.96	3.96	19.81	19.81	15.55	15.55
Grid reinforcement and extension	0.00	0.00	0.00	0.00	0.00	0.00	2.95	5.20	2.57	4.52	8.62	15.18
Total grid-level system costs	3.10	2.76	1.34	1.34	0.56	0.56	18.60	30.23	34.05	45.39	57.89	71.71

Source: OECD/NEA, *Nuclear energy and renewables: System effects in low-carbon electricity systems*, 2012.

VRE supplied just over 10% of UK electricity in 2014 and could provide nearer 22% in 2020, rising on the *Gone Green* scenario to 39% in 2030 and 34% in 2050. Interpolating from the OECD figures suggests extra system costs from VRE could be £650 million in 2014, £2.2 billion in 2020, £5.2 billion in 2030 and £6.1 billion in 2050.

Since the Lords Committee inquiry, the International Energy Agency has also published a major study on the issue, focusing primarily on how power systems can be made amenable to high levels of VRE.[57] Unfortunately, it does not separate out the system costs of VRE from their higher LCOE. They conclude that the total system cost of a legacy system would be increased by $20–25/MWh if VRE provided 45% of output, equivalent to £4.5–5.6 billion for the UK. However, this cost could be brought down to $14–18/MWh as the legacy fleet of generators is adapted to partner the renewables and reduced further to $11–15/MWh if demand-side integration measures equal to 8% of demand were introduced.[58]

Given such conflicting estimates and analyses it is easy to understand the bewilderment of the Lords committee!

However, an important series of papers by Lion Hirth et al. – several of whom worked on the IEA study – is helpful in clarifying the situation. They carried out a comprehensive study of the literature on engineering estimates of system costs. But most important, they point out that instead of looking at the system costs, which are difficult to disentangle, we can look at the value placed by the market on VRE. In a competitive system (or one with a rational system operator and rational tariffing), the market value of VRE will reflect the costs it imposes on the system.[59] Electricity may be physically homogeneous but its value – the price actually paid for it – depends on a) when, b) where and c) with what lead time/predictability it is produced. In north-west Europe, for which they analysed actual price data and modelled the system, there is a market in electricity with prices varying hour by hour and in different locations, and also a futures market enabling the impact of lead times to be analysed.

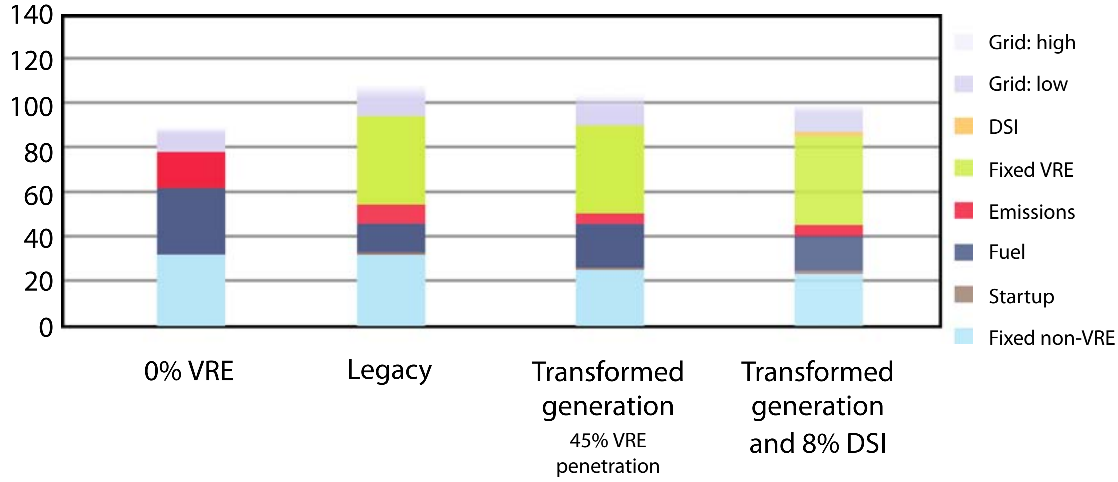

Figure 1: Total system cost at different degrees of system transformation

US dollars/MWh for a test system. DSI, demand side integration. Source: IEA.

Overwhelmingly the most important factor affecting the value of VRE turns out to be 'when'.

Because electricity cannot be stored (except at prohibitive cost), the price of electricity at any point depends on the supply and demand for electricity at that time. When the wind blows and sun shines the available supply of electricity increases. This drives down the wholesale price of electricity. Consequently the price realised for electricity from these variable renewable sources is usually below the average price of electricity from all types of generator over the whole year.[60]

This lower price received for VRE is the counterpart of the higher cost that it imposes on the system, namely the reduced utilisation of conventional capacity that has to be available for when the sun and wind are not generating. When wind and sun *are* generating they displace electricity that would have been produced by conventional plant. That saves the fuel costs of that plant but incurs the 'opportunity cost' of underutilising the capital investment in that plant.

Hirth calls this the 'profile cost' and it is overwhelmingly the most important cost imposed by VRE on the rest of the system. If the conventional plant was built before government began to promote VRE then the owners of the conventional plant may bear the cost of under-usage of their plant. But when it needs to be replaced, investors in new plants will need to recoup the full cost of their plant over a lower output – when wind and sun are not generating electricity. That higher cost will have to be passed on to consumers.

There are two other factors related to capacity that affect system costs. Any grid system needs sufficient 'assured' capacity to meet peak demand and possible outages of major plants. Conventional thermal and nuclear plants can be relied on to provide 85–90% of their capacity. Wind and solar can only be relied on to contribute some 15–20% of theirs, so additional underutilised conventional capacity is required.

Moreover, increased VRE capacity can lead to output exceeding demand. This happens when VRE produces at high capacity levels and demand is low, for example on a particularly windy day in summer. In this case some VRE will have to be shed, which very often means paying suppliers to switch off. In the UK, £90.5 million was spent in 2015 on paying windfarms to switch off.[61] That too is an opportunity cost of under-use of capital; in this case the capital invested in wind or solar generators.

As the IEA study emphasises, the system cost of integrating VRE can be mitigated by a range of measures to help smooth out the profile of load, less VRE, which the dispatchable generators need to supply. These measures include: diversifying wind sites, building interconnectors, making use of hydro storage where available, replacing conventional baseload generators by load-following generators, and facilitating and incentivising demand-side response. The study makes clear these measures are much simpler to incorporate in the expanding electricity system of an emerging economy than in a mature country like the UK. But they all come at a cost.

Hirth's analysis of prices received by VRE in the north-west European market, modelling of that market and the review of engineering estimates converge on the conclusion that 'at 30% wind market share, electricity from wind power is worth 30–50% less than electricity from a constant source'.[62] So even if wind attains 'grid parity' it will be necessary to achieve further reductions in levelised costs of 30–50% to make it economically competitive with conventional power sources.

Unfortunately, no similar studies appear to have been done for the UK market. But the reduction in value for VRE in the UK is unlikely to be less than this given that our market is less well connected to neighbouring markets and, in particular, cannot rely on Scandinavian hydropower, which can partly compensate for the variability of wind and solar. On the basis of Hirth's figure the extra system costs at 30% wind penetration for the UK would be £1.7 billion to £2.8 billion. Moreover, this figure does not seem to take into account the additional transmission costs to bring wind to users.

Hirth's study also concludes that:

- Wind power will play a limited role (compared to some political ambitions)
- VRE does not go well together with nuclear power or CCS – these technologies are too capital intensive.

DECC has yet to take on board these implications of reliance on VRE.

5 Is carbon capture and storage too costly to use or too costly to forego?

The official pathway to decarbonising the UK economy depends on CCS. There are three problems with this.

CCS may not be available CCS is based on a very conventional chemical process, so it has been assumed that it would be straightforward to industrialise. But that has not proven to be the case. There is only one industrial scale plant operating in the world – the Boundary Dam power plant in Fort Saskatchewan, Canada. That has the advantage of supplying carbon dioxide for enhanced oil recovery, which provides a market and avoids the need for special storage reservoirs. Nonetheless its economics have proved disappointing. The project cost US$1.3 billion,[63] but in the process reduced the capacity of the generator by 25% and 40 MW.[64] The resulting parasitic load means that the project cannot even generate an operating profit.[65] Elsewhere, CCS projects have been abandoned in Sweden, Norway and Australia. In the UK the first attempt to fund a pilot study failed to find a suitable candidate despite the £1 billion grant on offer. The process was repeated and two candidates found. Then one of them, Drax, announced it was pulling out and finally the then Chancellor cancelled the £1 billion offer in his 2015 Autumn Statement.

CCS is energy intensive Among the problems associated with CCS are the fact that it is highly energy intensive so it automatically reduces the efficiency of any power station – possibly by 25% or more. It requires a pipeline network to take the CCS to a storage location; such locations are not as readily available as hoped. Also, carbon dioxide can be lethal but undetectable if it leaks from pipeline or reservoir so CCS facilities will not be popular on land.

CCS may be too expensive As Hirth has shown, the major system cost of VRE is to reduce the capacity utilization of dispatchable plant. So the higher the capital costs the greater the system costs incurred through underutilisation which will further undermine the economics of CCS.

Yet without CCS the cost of decarbonising the power system may be prohibitive. According to Carbon Connect: '…meeting the UK's carbon targets without CCS would cost the UK around £30–£40 billion more each year… roughly doubling the expected annual costs'.[66] Even the CCC admits[67] that 'Our estimates, and those of others, suggest the cost of meeting the 2050 target would be twice as high without CCS'.[68]

The only available alternative to CCS is much greater reliance on nuclear. There are technical problems in using nuclear to provide dispatchable capacity, although France does use some of its nuclear capacity for load following. But even if nuclear plants can be made more flexible they suffer from the same problem of high capital costs, making part-time working prohibitively expensive.

A strategy that depends on a technology which does not yet exist in practice, which promises to be cripplingly expensive if developed, but without which costs may double, is verging on the reckless.

6 Is the UK cutting emissions cost-effectively?

So the costs of trying to meet the Climate Change Act targets are far higher than DECC or most climate activists have been prepared to admit. Without questioning whether those targets are desirable it is perfectly reasonable to question whether there are less costly ways of reducing carbon emissions.

It should be noted that the four main factors which have reduced UK emissions have not been the result of deliberate carbon polices. They achieved greater reductions in carbon emissions, albeit unintentionally, than all the measures deliberately introduced to cut those emissions. They are:

- the great recession resulting from the financial crisis after 2008.
- the outsourcing of carbon emissions to China and others since the late 1990s, as we imported carbon-intensive manufactures from emerging economies instead of manufacturing them ourselves.[69]
- the 'dash for gas' from the late 1980s onwards when gas displaced coal in UK electricity generation.
- closure of coal-fired power stations because of EU Directives to prevent emissions other than carbon dioxide.

Clearly, no government would want to prolong recession just to reduce carbon emissions, although Green campaigners who advocate 'an end to growth' do implicitly or even explicitly call for 'planned contraction'.[70]

Nor would any government deliberately encourage further deindustrialisation of the UK economy to outsource carbon emissions, although, paradoxically, the commitment under the Climate Change Act unilaterally to burden UK industry with the cost of decarbonisation will accentuate that process. Had the UK not outsourced much of its manufacturing to Asia, UK emissions would have risen instead of falling.[71] Indeed on the basis of what we consume, the UK's carbon footprint has actually *increased* despite all the measures so far taken to reduce it. The government is lucky that the definition of carbon emissions happens to be based on each country's production rather than its consumption. But for environmentalists to conceal the minimal progress so far by hiding behind this definition is somewhat disingenuous.

Only the third of these unintended carbon-dioxide-saving events – replacing coal by gas – offers scope for further cost-effective carbon savings. Britain still obtains nearly a third of its electricity from coal. So there is scope to go further in replacing

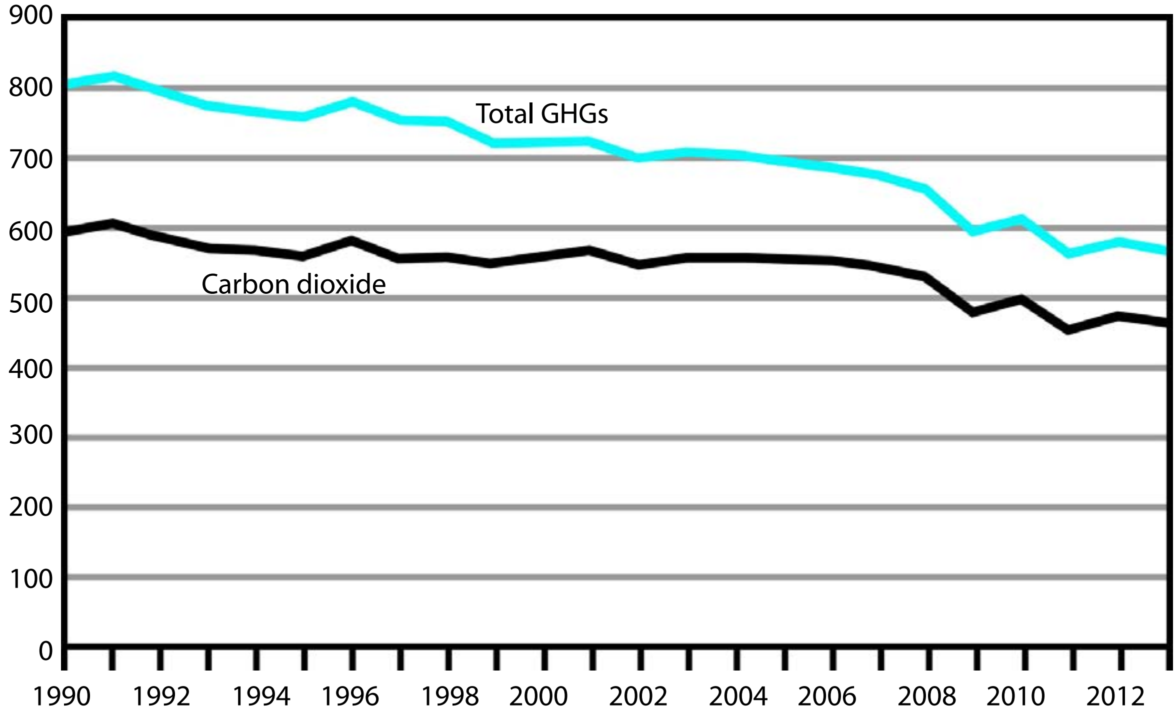

Figure 2: Emissions of greenhouse gases, UK and Crown dependencies, 1990–2013 (MtCO2e). Source: *Final UK greenhouse gas emissions national statistics 1990–2013*.

coal by gas. Gas emits only half as much carbon dioxide as coal per unit of electricity and is the next cheapest source of electricity. So this would undoubtedly be more cost effective than any of the existing decarbonisation policies. Should shale gas exploration prove successful there would be even more reason to pursue this strategy. DECC's central forecast assumes that the UK will generate as much electricity from gas in 2030 as in 2015.[72] But they prefer to replace coal by renewables even though that is more expensive. This is presumably because to meet the path to 80% decarbonisation by 2050 they will have to start phasing out gas well before then, or using it only in conjunction with CCS. And they clearly do not believe that CCS can be made cost effective enough to make a further dash for gas worthwhile.

Under the EU Large Combustion Plant Directive coal-fired generators are obliged within a certain time either to retrofit expensive scrubbers to remove SO_2, NOx and particulates or to close. A number have closed – most recently the largest UK conventional generator, Longannet , in March 2016 – and the remainder are likely to follow. Thereafter there will be no scope for further savings by closing coal-fired power stations.

The immediate effect of these closures has been similar to the dash for gas in that they were effectively replaced by greater use of existing gas generators. This was one

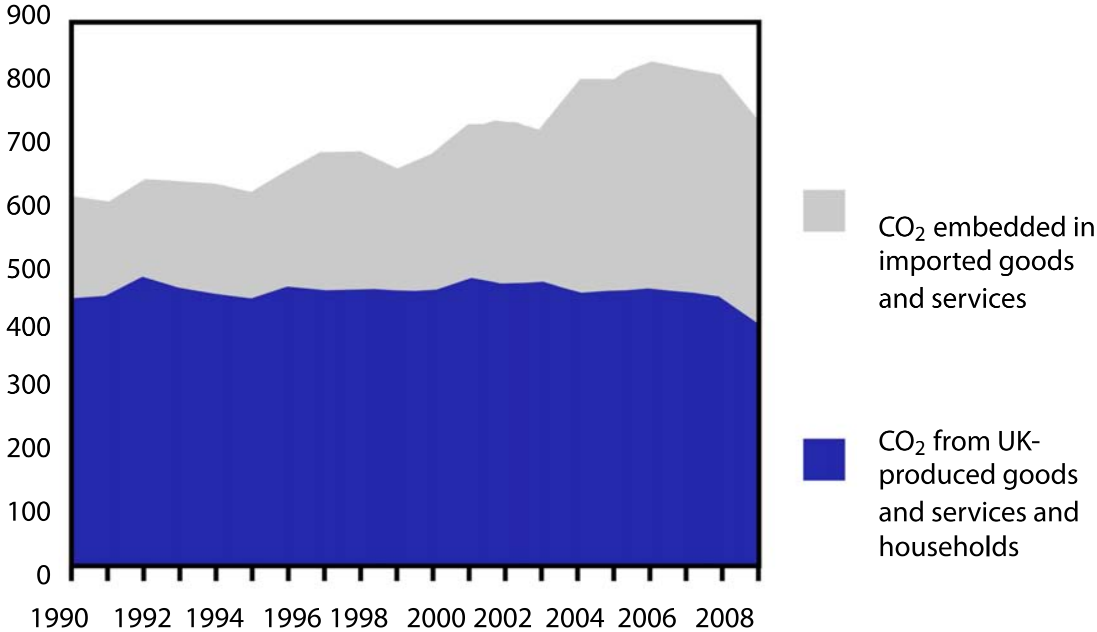

Figure 3: UK domestic carbon dioxide emissions plus emissions embedded in imported goods and services ($MtCO_2$)

Source: University of Leeds and Centre for Sustainable Accounting.

reason for the unexpectedly large fall in UK emissions in 2014. However, it also means that the level of spare capacity in the UK system is unprecedentedly low. This is one reason why DECC has had to introduce capacity auctions. Paradoxically, the auctions resulted in DECC contracting with coal-fired power stations to remain on standby instead of closing completely. Coal capacity accounted for 19% of the capacity in the first auction.[73] When run on stand-by or ramped up and down to offset fluctuations in wind capacity they will actually emit *increased* amounts of carbon dioxide per unit of electricity. However, given that they will only be used part of the time they will no longer be major emitters.

As for policies to decarbonize the UK economy: are they cost effective? The UK target set by the Climate Change Act is simple: reduce emissions by 80% by 2050. Yet, in addition to that ultimate target, there is a bewildering array of subsidiary targets, subsidies, taxes, permits and regulations. There are carbon budgets for each of the five-year periods up to 2050, there are targets for renewables use in particular sectors (notably electricity generation and transport fuels) and there are different levels of subsidy for different types of renewable energy.

Some of the targets are set by the EU. They are superfluous given the UK's commitment to reduce total carbon dioxide emissions by 2050. So once the UK has left the EU it will be able to abandon these surrogate targets without resiling from the Climate Change Act, while possibly continuing to participate in the Emissions Trading Scheme.

Some of the targets, for example for renewables use in electricity generation, may produce significantly lower carbon savings than might appear likely. For example, generating 30% of our electricity from renewables will not necessarily result in 30% less carbon being emitted. This is because renewables are intermittent. Sometimes the sun does not shine nor the wind blow, and the strength of both can fluctuate over short periods. So it is necessary to maintain back-up 'dispatchable' capacity, normally provided by fossil-fueled generators. Some of these – the 'spinning reserve' – will be fired up all the time (so emitting some CO_2) so they are capable of coming fully on stream more or less instantaneously. This is necessary to prevent frequency loss if there are fluctuations in wind strength. Other back-up capacity, which may be fired up at somewhat longer notice, will use gas less efficiently than if used more continuously – just as cars use fuel much less efficiently when constantly starting and stopping in traffic jams. The type of gas turbines most suitable for this – open-cycle gas turbines (OCGT) – is not the same as the combined-cycle gas turbines (CCGT) normally installed to generate baseload electricity. The wear and tear using CCGT for back-up will increase maintenance costs and shorten their useful life.

Professor Gordon Hughes gives numerical examples comparing carbon dioxide emissions from a CCGT plant with those wind power backed up by OCGT.[74] He shows that where OCGT gas turbines are used for baseload generation, wind turbines operating alongside will result in an increase in emissions. Where either OCGT or CCGT gas turbines are used for mid-merit generation, using wind power alongside will slightly increase emissions. Only in the case of peak generation, where OCGT turbines are invariably used rather than CCGT, does wind not result in increased emissions. His findings have been disputed by Gross et al., but essentially on the basis that in practice wind power would be backed up primarily by heritage CCGT plants, new CCGT plants and very little OCGT.[75] In the long run it is not clear whether new CCGT plants would be built for very intermittent and occasional use alongside a high level of wind generation.

A US study by Bentek Energy showed that a regional generating system with a high penetration of wind resulted in a net increase in carbon emissions.[76] In that case, the back-up dispatchable power was supplied by existing coal-fired generators. Both the Bentek study and its critics the American Wind Energy Association have a vested interest in their respective arguments.[77] Unfortunately it is difficult to find a dispassionate critique. It is unlikely that the consequences for emissions of increasing wind power in the UK generating mix would be nearly so perverse given our greater reliance on gas-turbine back-up. Nonetheless, studies of the Irish[78] and Danish[79] experiences suggest that the reduction of emissions by switching to intermittent renewable generation is offset to a non-negligible degree by the need for conventional fossil back-up.

Very different levels of subsidy apply to different types of renewables. The government has acknowledged that the cost per ton of carbon dioxide abated (that is, not emitted) as a result of different technologies is both high and variable (see Table 5).[80]

Table 5: Cost per ton of CO_2 abated by different technologies in 2014

Technology	Cost £
Onshore wind	65
Offshore wind	121
Solar	110

These figures probably omit the system costs of intermittent renewables (negligible for biomass, highest for solar in the UK) as well as the offsetting reduction in carbon savings due to the need to ramp up and down inefficient back-up capacity which, like stopping and starting a car, is fuel inefficient.

To achieve a given target, the obvious course would be to rely on the lowest-cost methods of reducing carbon emissions until more competitive options become available. When challenged as to why they do not do so, DECC gives two reasons:

- The scope for deploying some less costly options is limited – in the case of onshore wind by environmental restraints.
- DECC now argues that investing in all these technologies will bring down their costs. The prospect of eventually reaching 'grid parity' is dangled before us with the implication that the more we invest in the immature technology the more rapidly technology will advance to low-cost maturity.

The assumption that if we invest enough in a technology its costs will come down sufficiently to compete with conventional power sources is wishful thinking. There is no guarantee that these technologies will become competitive. Indeed, so far the big technological advances have come in fossil fuels – notably fracking for shale oil and gas.

In any case it is clearly an ex-post excuse for investing heavily in high-cost technologies. Had the original motive genuinely been to drive down costs so that we could benefit from mature and competitive technologies, DECC would have examined what minimum or optimum level of investment was needed in uncompetitive technologies to drive down costs.[81] To invest in a high-cost technology more than is likely to be needed to bring down its costs is irrational for the reasons outlined next:

Long-term subsidies Renewables subsidies involve a commitment to go on paying that subsidy (or guaranteed price); for 15 years in the case of wind and solar farms and reportedly 35 years for the eye-wateringly expensive tidal lagoon.[82] So the more we deploy technologies while they are still uncompetitive the greater the long-term burden on the British taxpayer/consumer even if costs for new projects do come down. When environmentalists talk of costs of such and such a technology becoming competitive within a few years, they never point out that we will still be burdened by the cost of subsidies for a decade or more.

More uneconomic energy now means less cheap energy later The greater the proportion of our needs Britain meets from the current high cost version of each technology – offshore wind in particular – the less scope there will be to deploy the lower-cost version if and when it ever materializes.

Helping our competitors We are making a free gift to our industrial competitors who will be able to deploy the low cost version of the technology (should it emerge) and compete with us while we are still burdened by the long term commitment to subsidise past investments in the high-cost version.

There is no evidence that DECC has ever been through this thought process. Instead it has ploughed ahead with investment in whatever green technology was fashionable or advocated by an influential political or industrial lobby. The most egregious example is the apparent willingness to go ahead with the Swansea tidal lagoon.

It is in any case ludicrous to suppose that the speed with which technologies mature will be much affected by the amount the UK invests. For example, the decline in the cost of photovoltaic cells is the result largely of overinvestment by Chinese manufacturers in anticipation of growth in the world market, of which the UK is only a modest part.

DECC's strategy of investing in a variety of different high-cost technologies is a consequence or symptom of the mishmash of targets, subsidies, taxes, permits and regulations that the department has established to achieve the UK's carbon targets. Economists are notorious for their ability to disagree with each other. However, there is a rare near consensus among market economists that this resort to multiple policy levers to achieve a single objective leads to gross inefficiency.[83,84] Tol et al. calculate that the profusion of EU targets and instruments creates 'inefficiencies in policy [that] lead to a cost that is 100%–125% too high'.[85]

Market economists of all political persuasions agree that the most cost-effective way to incentivize decarbonisation is to set a price on carbon emissions. The carbon price can be set:

- by imposing a carbon tax that would be set to rise over time[86]
- by issuing tradable permits to emit carbon, with the number of permits set to decline over time and their price set in the market.

The EU has adopted the second route and set up the Emissions Trading System

(ETS). Large users of fossil fuels need a permit for every ton of carbon dioxide they emit. The total number of permits the authorities issue each year is set to decline steadily to bring the total emissions down to the targets agreed by the EU.[87] Permits may be bought and sold. Some companies may be able to reduce their emissions at less cost to themselves than the market value of these permits. So they will be able to sell their excess permits at a profit. Other companies who find it more expensive to reduce emissions than the cost of buying extra permits will buy some in. This creates a market incentive to ensure that the required reduction in emissions is achieved at the lowest cost to the economy.[88]

Given such a system, the effect of setting additional targets for renewable use or introducing subsidies and taxes to promote specific kinds of renewables or emission reductions can only increase overall costs. By definition, such incentives must induce some companies to make reductions in emissions that cost more than the market value of a permit. That in turn will reduce demand for permits, so lowering their price. The price of permits will decline until other companies decide this makes it more attractive to use or buy in permits to emit more carbon rather than make the additional carbon savings that would have been profitable at a higher permit price. The amount of carbon emitted will be unchanged, since that is set by the number of permits issued. But savings in emissions that cost a lot to make will have replaced savings that could have been made more cheaply.

Consequently, much of the UK's self-inflicted carbon austerity with its multiplicity of targets:

- does not save a single extra ton of carbon (since every extra ton we save releases a permit enabling others elsewhere in the EU to increase emissions by a ton)
- increases the cost to the UK of achieving its ultimate carbon emission target,
- effectively subsidises our competitors in achieving their emission reduction targets.

The price of ETS permits is currently £6/tonCO_2. This is only a fraction of the cost of saving a ton of carbon, even for the least expensive renewable shown in Table 1. This gives an indication of the scale of the inefficiency of British policy.

In theory the UK could have reduced emissions for £6/ton by buying in ETS permits and cancelling them. Instead our policies cost on average about ten times that amount for every ton of carbon dioxide abated.

Of course, if the UK or other countries did buy in permits on a large scale instead of subsidising renewables, that would drive up the price of permits. (The same would be true if the ETS managers reduced the number of permits issued each year.) But that would incentivise industries covered by the ETS scheme to find least-cost ways of reducing carbon emissions. The permit price would have to rise a long way before it cost us as much as even the cheapest of the UK's current policies. Either the ETS carbon price would rise until it justified current investment in renewables or other industries would find ways of making carbon savings at a lower cost.

Enthusiasts for micro-managing industry through detailed renewables targets argue that the low price of carbon permits is proof that the ETS scheme has failed. They even urge that the supply of permits be further restricted below the currently planned level. But the whole purpose of a permit system is to set a quantitative limit on carbon emissions each year, gradually reducing towards the EU target level. The permit price has fallen because the recession has reduced emissions more rapidly than anticipated. The pain of the recession has enabled (or forced) industry to reduce emissions in line with the path to the target without having to incur so much additional cost to reduce emissions by other means.

Some are concerned that as economies recover from the recession and the Eurozone crisis, emissions will tend to increase. This could sharply drive up the price of permits unless business has begun to economise on carbon emissions in anticipation of this. If the concern is to stabilize the carbon price it would have been better to institute a progressively rising carbon tax reflecting the estimated social cost of carbon. This might well be superior to the ETS. (It would certainly be much simpler since a carbon tax can be implemented at the point of production or import of hydrocarbons whereas a permit system requires detailed monitoring of emissions firm by firm. This also renders it much more vulnerable to rent seeking, lobbying and corruption.) But a carbon tax too would obviate the need for multiple targets, differential subsidies and complex regulations.

The UK is now in the bizarre position of having a carbon tax floor as well as participating in the ETS. There is a case for one or the other but no case for both. The tax may reduce UK carbon emissions, but, as explained above, to the extent that it does so it will release permits too, which will simply allow industries elsewhere in the EU to emit more carbon at lower cost. Although presented as a 'green' measure, its sole impact will be to raise tax revenue for the Exchequer at the expense of making British industry less competitive than our European rivals.

Notes

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5. CCC Fourth Carbon Budget Review, Technical Report p. 30
6. 'Implications of the Paris Agreement for the Fifth Carbon Budget – Letter from the CCC to Rt Hon Amber Rudd', 28 January 2016, p. 3
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8. Brenda Boardman, *Fixing Fuel Poverty: challenges and solutions*, 2010.
9. DECC *Estimated impacts of energy and climate change policies on energy prices and bills*, November 2014.
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12. Office for Budget Responsibility, *Economic and Fiscal Outlook*, November 2016
13. Evidence to the Energy and Climate Change Select Committee, 23 January 2013.
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24. CCC *Energy, Prices and Bills*, 2014. Technical Annex footnote p. 8.

25. In its Progress Report of June 2015, CCC puts the extra transmission cost in 2014 at £450 million.

26. CCC, *Energy Prices and Bills* 2014, Technical Annex p. 8.

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28. Poyry, *Analysing technical restraints on renewable generation to 2050*, 2011. However, the figures for 30% and 40% penetration in 2030 are not in the published report but are given in the Technical Appendix. See previous footnote.

29. Letter from Matthew Bell to Peter Lilley, 22 September 2015.

30. Letter from Matthew Bell to Peter Lilley, 6 October 2015.

31. 'Besides transmission, the costs related to the increased intermittency of electricity sources also need to be taken into account. These include the costs of distribution interconnection, bulk storage, smart grids and additional conventional generation (to ensure balancing and reliability). Overall, the Committee on Climate Change estimated that the combined costs of transmission upgrades and other flexibility measures related to a 30 to 64 per cent share of electricity from renewables by 2030 would be between £5 and £5.9 billion per year (CCC, 2011b; Pöyry, 2011).' Samuela Bassi, Alex Bowen and Sam Fankhauser, *The case for and against onshore wind energy in the UK* , June 2012.

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80. Reply by Lord Bourne, Under Secretary of State, DECC to Oral PQ from Viscount Ridley 24 June 2015, Lords Hansard col 1584. These costs almost certainly do not include the system costs of each technology which, according to the OECD, are particularly high for solar.

81. The CCC has belatedly, but to its credit, recognized that this issue needs to be addressed, and commissioned a study: BVG Associates, *Approaches to cost-reduction in offshore wind*, 2015. Available at: www.theccc.org.uk.

82. Michael Kavanagh and Jim Pickard, 'Budget 2015: Favourable tide for hydroelectric lagoons'. FT, 18 March 2015. http://www.ft.com/cms/s/0/68930972-cd7a-11e4-a15a-00144feab7de.html#axzz3eYlaoAqr

83. Samuel Fankhauser, Cameron Hepburn and Jisung Park *Combining multiple climate policy instruments: how not to do it*, Centre for Climate Change Economics and Policy Working Paper No. 48, Grantham Research Institute on Climate Change and the Environment Working Paper No. 38, February 2011.

84. Tinbergen, J. *On the Theory of Economic Policy*, North Holland, 1952.

85. Richard S J Tol, Thomas F. Rutherford, Christoph Böhringer *The EU 20/20/2020 targets*, *Energy Economics* 2009; 31: S268–S273.

86. A rational method of doing so is proposed by Ross McKitrick in *An evidence-based approach to pricing CO_2 emissions*, The Global Warming Policy Foundation Note, 2013

87. For phases 1 and 2 of the EU ETS, member states determined the amount of allowances available based on estimates of emissions in the sectors subject to the ETS. Most countries overestimated the base level of emissions so over issued permits – a problem exacerbated by the recession – so the price fell almost to zero. In phase 3 these problems have been addressed and the number of emissions is set to reduced by 1.74% pa.

88. At least it would in theory if permits were auctioned. In practice most are allocated by governments, which leads to distortions and rent seeking.

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