REPORT TO THE COMMITTEE ON CLIMATE CHANGE

OF THE ADVISORY GROUP ON COSTS AND BENEFITS OF NET ZERO

Paul Ekins, Chair

with grateful acknowledgement of the many important contributions of members of the Advisory Group

CONTENTS

1. Remit and modus operandi

The Advisory Group on the Costs and Benefits of Net Zero was set up by the Committee on Climate Change (CCC) in the context of the UK Government's request to CCC to report on the desirability of setting a 'net zero' target for UK greenhouse gas (GHG) emissions and by what date. The membership of the Advisory Group is given at Annex 10.

The Terms of Reference of the Advisory Group were to:

1. Provide general commentary and advice on formulating and presenting an approach to assessing the costs and benefits of setting a net-zero emissions target in the UK, both those that can be quantified and those that cannot. That should include identifying risks of over- or under-stating costs (e.g. given the difficulty in predicting the pace and nature of technological and social innovation).
2. Provide advice on sources of evidence the CCC should draw on to assess costs and benefits of net-zero emissions targets for the UK, and what degree of confidence can be attributed to these.
3. Provide critical review and advice across a number of specific issues, including:
    a. Which costs and benefits of net-zero emissions targets should be considered, including non-GDP costs/benefits.
    b. What approach should be taken to assessing costs and benefits (should they be quantified or addressed qualitatively, and how), how robust are different approaches, and how can they be linked to different emissions reductions targets.
4. Provide critical review and advice on emerging CCC analysis of costs and benefits and how it should be interpreted.

The Advisory Group met three times in January-March 2019 and each of its members submitted papers on different aspects of the topic under consideration. Edited versions of these papers appear as Annexes to this report, which was written by the Chair.

2. Introduction

There are many kinds of costs related to climate change and the reduction of the anthropogenic emissions that contribute it. This report explores the costs and benefits of the UK reducing greenhouse gas (GHG) emissions to 'net zero' (i.e. remaining emissions are offset by removals of GHGs from the atmosphere). 'Net zero' globally is a necessary condition of stabilising average global temperature at any level. This report is concerned with the costs and benefits of doing it by the middle of this century such that average global temperatures are kept well below 2^{o}C, as envisaged by the Paris Agreement on Climate Change.

Relevant costs and benefits of 'net zero' include (avoided) climate damage costs, (avoided) climate adaptation costs, (avoided) other damage costs, e.g. air pollution (when they are called co-benefits of GHG emission reduction), and the costs of emission reduction (CER). The most important fact about CER, as will become apparent below, is that they are *dynamic* (they change over time) and *endogenous* (how they change depends on the policies and actions of government, business, other social groups and individuals).

This report is structured as follows.

Section 3 sets out the international context within which the UK is seeking to reduce its GHG emissions and considering the adoption of 'net zero' as a target for the middle of this century (2045-2055, but hereafter referred to as 2050). International mitigation action outside the UK will be crucial not only in meeting the Paris Agreement temperature target (emission reduction by the UK alone would have a negligible effect on this), but also in respect of the non-climate costs and benefits of the UK achieving 'net zero'.

Section 4 explains the concept of 'resource costs': the real expenditures that are required to meet 'net zero', over and above those required to meet the current (80% reduction) GHG emission reduction target. These costs are often presented as marginal abatement cost (MAC) curves. Their most crucial characteristic is that they change over time, dependent on how and how fast the different technologies described by them are developed and deployed, i.e. they are endogenous.

It is envisaged that the systematic implementation of low-carbon technologies will lead to the phenomenon of Clean Growth, which is a major plank of the UK Government's Industrial Strategy. Section 5 will briefly describe the thinking behind this strategy and assess the prospects of it being realised in practice. This leads into a broader discussion of the macro-economic implications of going for 'net zero', which is the subject of Section 6.

One of the characteristics of many low-carbon technologies is their greater capital intensity than the fossil fuel technologies they are replacing. This throws into sharp relief the issue of how these technologies are to be financed and the costs of such financing. This is the subject of Section 7.

Many other effects on society may be expected from large-scale GHG emissions reduction. These include physical health benefits from reduced local air pollution from stopping burning fossil fuels, from healthier diets with less meat and processed food, and from greater levels of active transport, and mental health benefits from living in greener, more liveable cities. These are called the 'co-benefits' of GHG emission reduction. They are the subject of Section 8.

Whatever the net costs or benefits of the shift to 'net zero', one thing is certain: it will involve a wholesale transformation of several of society's most important socio-techno-economic systems: energy, transport, land-use, food and buildings, to name just five. Such a transition will entail fundamental structural changes in the economy, which may be masked by focusing only on the net effects. Similarly, there will be winners and losers. These changes will need to be handled fairly if the transition is to win social acceptance. These issues form the subject matter of Section 9.

The transition to 'net zero' by 2050 will not happen by itself. It depends totally on public policy, working in partnership with business and the whole innovation system: to develop and deploy the required new technologies at the necessary speed and scale, and to stimulate the consumer demand to pull these technologies through markets at scale. What policies are implemented, and how, will largely determine the costs of the transition, and whether it is achieved at all. Some of the desirable features of such policy are described in Section 10.

Section 11 concludes and gives recommendations and advice to the Committee on Climate Change (CCC) on the basis of the issues discussed in the report.

It will be seen that this report covers an enormous amount of ground. To keep it readable and to a manageable length it can only summarise the huge literatures that underpin its arguments. The arguments are further developed in the Annexes, which consist of longer papers from members of the Advisory Group in their areas of particular expertise. The end result is intended to provide an overview of the major issues related to the costs and benefits of moving to 'net zero' and derive advice.

3. Relation to international mitigation action

The Paris Agreement committed countries to keep the average global temperature increase on pre-industrial levels to 'well below 2°C'. As shown in Figure 1, the IPCC 1.5°C report made clear that going beyond a temperature increase of 1.5°C would significantly increase the risks of substantial damage from climate change – the report actually cites estimates of the extra damage caused in 2100 by 2°C as opposed to 1.5°C as USD 15-38.5 trillion (2.3-3.5% of Gross World Product).[1]

Apart from clearly being very big numbers, the utility of such monetary estimates is doubtful, partly because their nature and extent is still very uncertain, but there is a non-negligible risk of them being catastrophic (the Weitzman 'fat-tail probability distribution' argument[2]), and partly because of what they include. For example, the utter misery experienced by millions of people in Mozambique, Malawi and Zimbabwe due to the devastation caused by Cyclone Idai in March 2019, quite apart from the resulting loss of life and subsequent diseases, simply defies monetisation, and the climate change in prospect without dramatic emission reduction promises much worse. If global warming increased from 1.5°C to 2°C: "risks across energy, food, and water sectors could overlap spatially and temporally, creating new and exacerbating current hazards, exposures, and vulnerabilities that could affect increasing numbers of people and regions" (p.12), there would be higher "heat-related morbidity and mortality" and "risks from some vector-borne diseases", the "proportion of the world population exposed to a climate change-induced increase in water stress" could be 50% higher", and "the number of people both exposed to climate-related risks and susceptible to poverty" could be "up to several hundred million by 2050". Moreover, "Populations at disproportionately higher risk of adverse consequences with global warming of 1.5°C and beyond include disadvantaged and vulnerable populations, some indigenous peoples, and local communities dependent on agricultural or coastal livelihoods." (all quotations from pp.11-12, Summary for Policy Makers [SPM], IPCC Special Report on *Global Warming of 1.5°C*). Many of these populations will have contributed little to nothing to the emissions that have caused anthropogenic global warming, so that there are powerful ethical, as well as economic, reasons for limiting it as much as possible.

It may be concluded, therefore, that keeping average global warming to 1.5°C rather than 2°C would be associated with substantial avoided climate damages, many of which would be visited on those who had made a negligible contribution to the problem.

[1] IPCC 2018 *Global Warming of 1.5°C,* Ch.3, p.256 https://www.ipcc.ch/sr15/chapter/chapter-3/
[2] See the non-technical discussion of this in Wagner, G. and Weitzman, M. 2015 *Climate Shock: the Economic Consequences of a Hotter Planet*, Princeton University Press, New Jersey, Ch.3

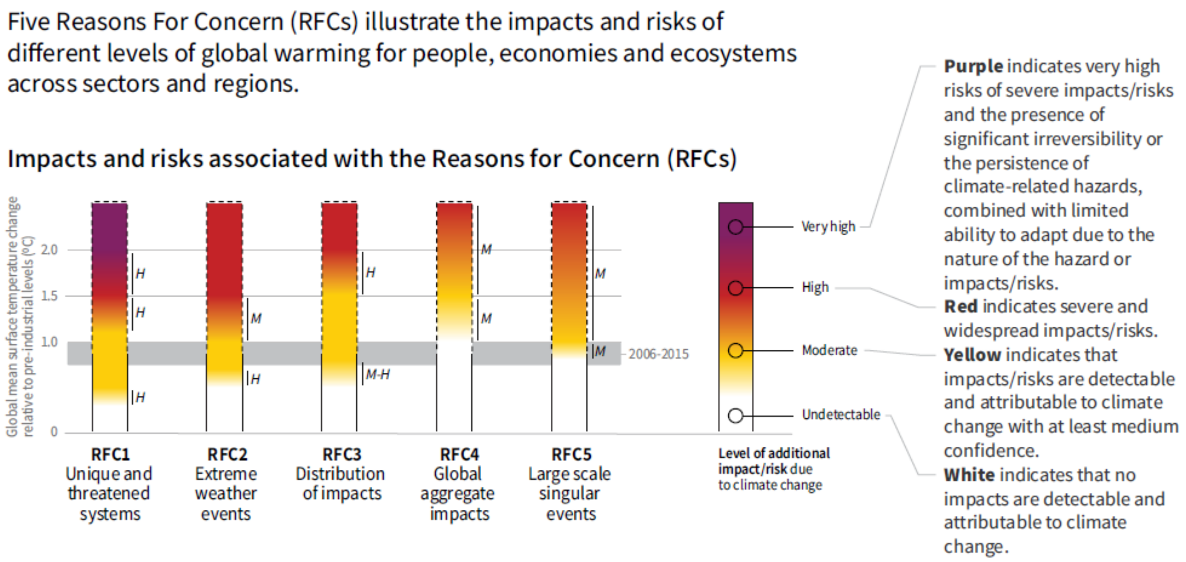


Figure 1: Illustration of increased risks from greater levels of global warming
Source: IPCC 1.5°C Special Report, Figure SPM2, p.13, https://www.ipcc.ch/sr15/chapter/summary-for-policy-makers/

The IPCC 1.5°C report makes clear that keeping average global warming to 1.5°C will require anthropogenic CO_2 emissions to fall to net zero by or shortly after 2050, with non-CO_2 greenhouse gas (GHG) emissions also falling after 2030, to reach around half their 2030 level in 2100.

It is well understood that the substantial reduction of global warming will require effort from all major emitters. It is of course true that if the UK were the only country in the world to reduce its GHG emissions to net zero, the effect on global warming would be negligible. But the power of the Paris Agreement is that nearly all countries have now committed to the 'well below 2°C' target. Moreover, the UN Framework Convention on Climate Change makes clear that countries have differentiated responsibilities to respond to the challenge of climate change. Some countries (the early industrialised countries) have contributed disproportionately more to the problem. Some countries through their wealth and technological capacity are better able to respond to it. The UK falls squarely into both categories.

In conclusion, therefore, the benefit side of the world limiting average global warming to 1.5°C is incalculable but likely to be very large. The payment of an affordable insurance premium to avoid such uncertain but potentially catastrophic risks would seem a reasonable ask. What constitutes 'affordable' forms the basis of the discussion below. The responsibility of the UK to lead in this effort is very clear. The only situation that would justify the UK shirking this responsibility would be if its costs were prohibitively high. It is to the consideration of these costs that this report now turns.

4. Resource costs of deep decarbonisation

As noted in Annex 1, the direct resource cost of emission reduction "is a measure intended to reflect the additional cost of all resources required to meet a carbon target over a given time period". This cost clearly depends on the extra measures that will be required to go from an 80% emission reduction by 2050 (the current UK target) to net zero. The difference between -80% and net zero is that for the latter emissions reduction options will need to be implemented in all emission-producing sectors, with any remaining emissions from any sector having to be offset by emission reductions elsewhere or withdrawal of CO2 from the atmosphere.

Annex 2 sets out the major emission reduction actions that are necessary for the deep decarbonisation envisaged in the Sky scenario of Royal Dutch Shell. These options are common to all such scenarios (including the CCC's net-zero scenarios) and comprise: electrification of final energy use (including for transport and a substantial share of heat) with zero-carbon electricity (renewables and nuclear); growth of new energy systems, and shifting to zero- or lower-carbon molecules (hydrogen, synthetic fuels, biogas) in hard-to-electrify sectors or uses; structural energy efficiency improvements; carbon capture and storage (CCS), perhaps with bioenergy to create 'negative emissions'; ending deforestation and emissions from land use change and drawing down carbon from the atmosphere into soils and extended forest cover.

There have been numerous attempts to estimate the costs of these options both now and how they might evolve in the future. Figure 2 illustrates one such attempt, with the estimated costs for 2030 arranged in a rising marginal abatement cost (MAC) curve. It will be noted that, as is common in MAC curves of this kind, the first tranche of carbon abatement (up to about 12 $GtCO_2e$ per year) is estimated to be available at negative costs. The total cost of abatement up to a certain level is given by summing the areas under all the bars up to that level. Figure 2 shows that up to about 35 $GtCO_2e$ per year the total cost of abatement will be roughly zero (the area of the bars below the zero-cost line is roughly equal to the area of the bars above it up to that level of abatement). Thereafter the costs of abatement are shown to rise quite steeply.

There are a number of reasons why MAC curves may underestimate the total cost of substantial emission reduction (e.g. later measures may reduce emissions less than estimated because of earlier savings, omitting policy or transition costs) but these are likely to be less important than uncertainties about the future costs of abatement themselves.

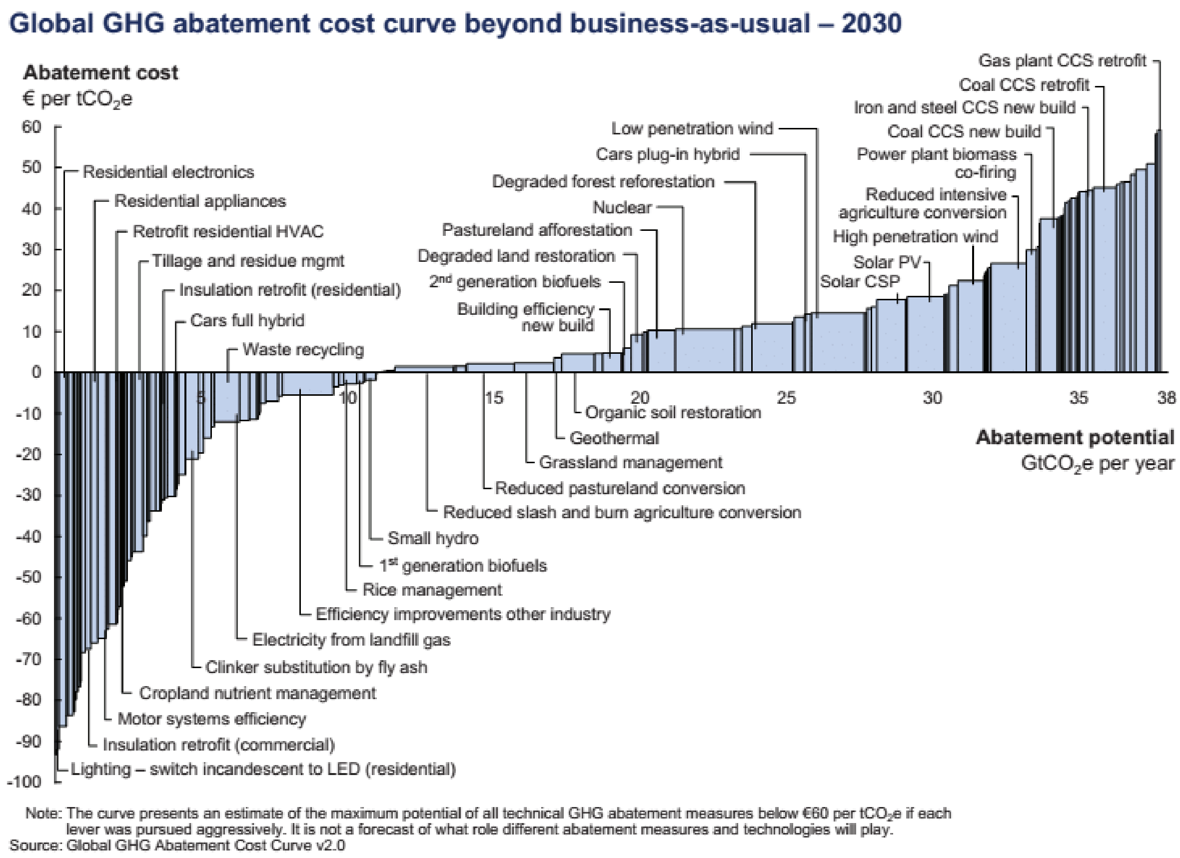


Figure 2: Marginal abatement cost curve
Source: McKinsey 2009 'Pathways to a Low-Carbon Economy', Exhibit 3.01, p.27
https://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/sustainability/cost%20curve%20pdfs/pathways_lowcarbon_economy_version2.ashx

Figure 3 shows a log-log 'learning curve' for photovoltaic (PV) technologies from 1980 to 2017, a period over which cumulative production increased by a factor of 10^5, and prices fell from about €40/Wp to around €0.3/Wp. Clearly there is likely to be a dynamic causal feedback between these variables – as more panels are produced costs of production fall, and as costs of production fall more panels are installed. This kind of cost dynamic has caused the International Renewable Energy Agency (IRENA) to conclude: "By 2020, all the renewable power generation technologies that are now in commercial use are expected to fall within the fossil fuel-fired cost range, with most at the lower end or undercutting fossil fuels."[3]

[3] IRENA 2018 'Renewable Power Generation Costs in 2017', https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf

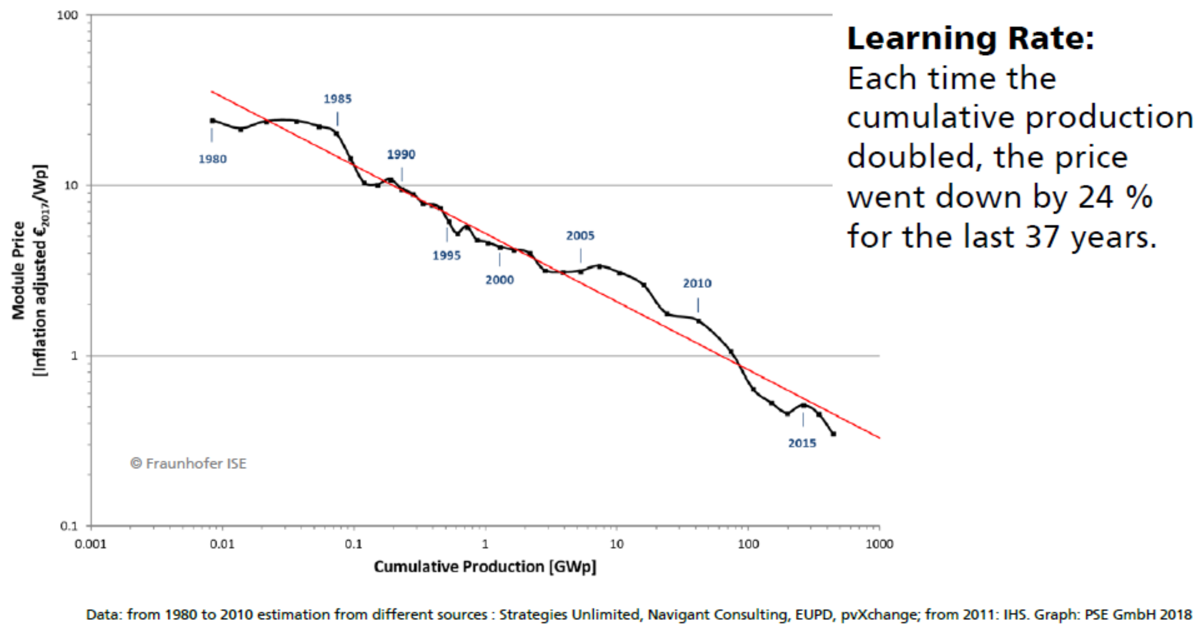


Figure 3: Learning curve for all commercial photovoltaic (PV) technologies
Source: Fraunhofer Institute for Solar Energy Systems, ISE 2018 'Photovoltaics Report', https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf

The UK experience with the cost of offshore wind is very much in line with such perceptions. The first offshore wind farms in the UK North Sea were commissioned in 2014 at £140-150/MWh. The lowest price in the most recent round of auctions came in at £57.50[4]. Comparison of these costs with the 'Low penetration wind' and 'High penetration wind' bars shown in Figure 2 is instructive. Figure 2 shows substantial 2009 estimates of abatement costs from wind in 2030; recent experience suggests that UK offshore wind farms will be competitive with fossil fuel plants when they come on stream in the North Sea in the early 2020s, i.e. their abatement cost will be zero.

Annex 3 explains the dynamics around these kinds of cost reductions. "Once a technology becomes sufficiently competitive, it starts to change the entire environment in which it operates and interacts. New supply lines are formed, behaviours change, and new business lobbies push for more supportive policies. New institutions are created, and old ones repurposed. As costs fall and expectations of market size increase, additional investment is induced and the political and commercial barriers to a transition begin to drop away. A tipping point is eventually reached where incumbent technologies, products and networks become redundant."

As Annex 3 shows, these dynamics have led many analysts and economists both to underestimate the pace of deployment of new technologies, and to overestimate their costs. Whether or not this is the case, it is most misleading to aggregate resource costs across different abatement actions and express them as a percentage of GDP, without clearly explaining that this does *not* mean that these costs would translate into a similar *reduction* in GDP if these abatement actions were implemented.

[4] https://www.carbonbrief.org/analysis-uk-auction-offshore-wind-cheaper-than-new-gas

Why this is the case is explained in Annex 1. How these costs actually play out in terms of their macro-economic impacts is discussed in section 6.

5. Clean growth

These are the kinds of arguments that have caused the UK Government to embark on an Industrial Strategy[5] that has 'clean growth' as one of its four grand challenges, with the bold definition: "Clean growth is growing our national income while cutting greenhouse gas emissions."[6]

Figure 4 shows in which sectors GHG emissions will need to be reduced.

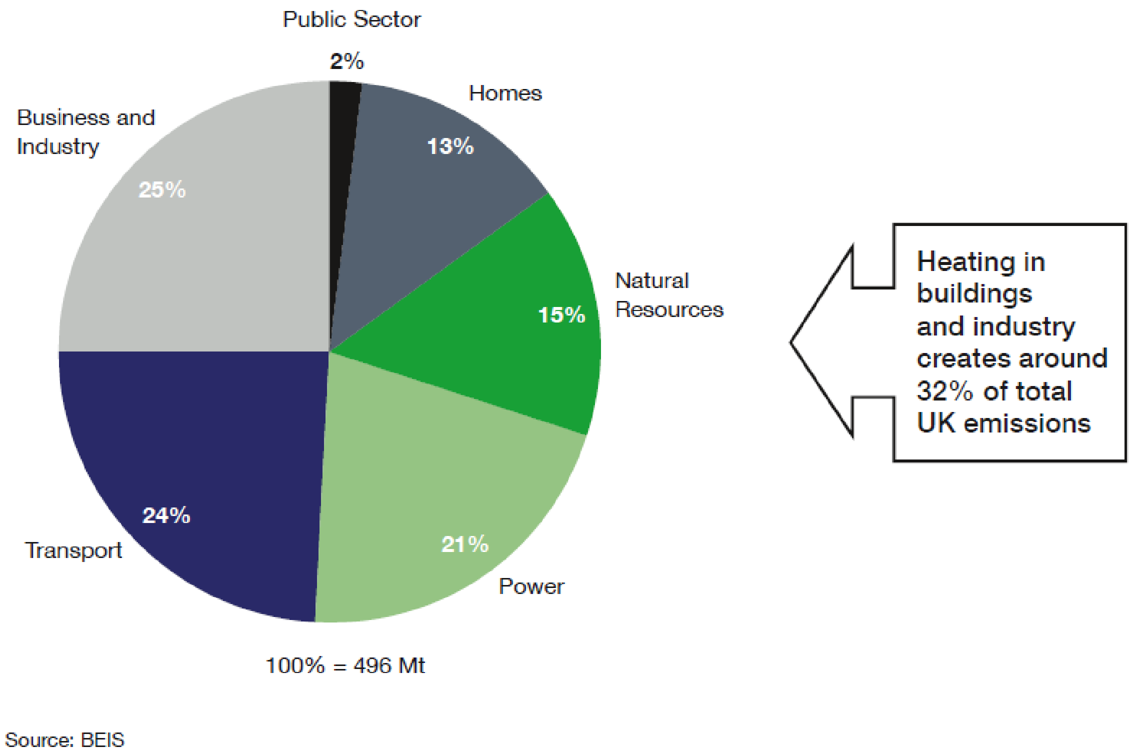


Figure 4: UK Emissions by Sector, 2015
Source: BEIS 2018 *Clean Growth Strategy*, Figure 2, p.9
(Note: Emissions from Natural Resources include those from agriculture, other land use and waste management.)

The Clean Growth Strategy discusses three broad 'pathways' of decarbonisation emphasising different elements that are also in the Sky net-zero emissions scenario discussed in the previous section: an electricity pathway, which uses 80% more electricity than in 2017, coming mainly from nuclear and renewables, to provide the energy for electric vehicles, household heating and much industry; a hydrogen pathway, in which hydrogen is predominantly used to heat homes and

[5] BEIS (Department of Business, Energy and Industrial Strategy) 2017 *Industrial Strategy*, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/664563/industrial-strategy-white-paper-web-ready-version.pdf
[6] BEIS (Department of Business, Energy and Industrial Strategy) 2018 *Clean Growth Strategy*, October 2017, as amended April 2018, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf

buildings, fuel vehicles and power industry; and an emissions removal pathway in which sustainable biomass power stations with CCUS (carbon capture use and storage) technology provide the main energy source. All these pathways also envisage significantly increased energy efficiency in homes, commercial buildings and industry, a flexible largely decarbonised electricity system, more district heating and many more ultra-low emission vehicles. While the major focus of the Clean Growth Strategy is the fifth carbon budget period (2028-32), it also looks beyond this to 2050. Although the pathways are cast in terms of an 80% reduction in GHG emissions, it is clear that they could be pushed further to deliver net zero emissions were this to be required, not least because "the Government believes the UK will need to legislate for a net zero emissions target at an appropriate point in the future, to provide legal certainty on where the UK is heading." (p.57)

While the Clean Growth Strategy looks in detail at how the emissions from the different sectors in Figure 4 can be reduced, it neither computes a resource cost for this emission reduction nor does it estimate the overall macro-economic implications. However, the Strategy states that its pathways "are consistent with current official economic growth and population projections" (p.153), and it clearly envisages that, as per the title of the Strategy, these pathways will contribute to, rather than undermine, economic growth. However, the Strategy also acknowledges that there may be impacts on the growth and competitiveness of the UK economy through: impacts on the timing and scale of investment spending; impacts from improvements in energy efficiency, and changes in expenditure on capital assets; reorientation of consumption patterns away from emissions-intensive products and towards more energy-efficient products; impacts from changes to energy prices; long-term benefits from innovation, including the development of nascent industries, associated spillover benefits into other sectors, and the increase in exports of knowledge and new technologies; indirect effects on growth through changes in exposure to energy price volatility and supply disruptions; transition costs that could materialise, for example the potential impact of stranded assets and any transitional unemployment; and multiplier effects associated with the above impacts, including any impacts on employment, (impacts list slightly abridged from the list on p.155 of the Clean Growth Strategy).

These effects act in different directions and their net effect can only be determined through the use of economic models, the nature and results from which are considered in the next section.

6. Macroeconomic costs of deep decarbonisation

Many macroeconomic models that have computed the costs of decarbonisation have generated sometimes not insignificant net costs (for example, the modelling results reported in the Summary for Policymakers of the IPCC WG3 AR5 assessments estimated global consumption losses of 2-6% in 2050 [median 3.4%] associated with an emissions trajectory that limited atmospheric concentrations of GHGs to 450 ppm CO_2e in 2100) through the following processes in the models. Investments for decarbonisation replace investment in capital equipment related to fossil fuels. The low-carbon technologies are more expensive than the fossil-fuel related technologies they replace, and this increases energy costs to households and firms, which reduces households' expenditure on other goods and services and the competitiveness of firms, which damages their sales in both home and export markets. Lower economic activity, income (GDP) and employment is the result. Moreover, this effect will be exacerbated if the investment in low-carbon technologies is greater than the investment in fossil-fuel technologies that it replaces, and other, more productive, investment is crowded out. This result may be mitigated through saving the ongoing costs of having to purchase fossil fuels, which is a greater economic benefit for fossil-fuel importing countries, when these fuels have to be purchased from abroad. In addition, the low-carbon technologies may involve greater domestic economic activity and employment than those they replace. However, for many models these mitigating effects do not compensate for the activity-reducing effects, and a net reduction in GDP is the result[7]. These arguments are illustrated in the flow diagram of Figure 5a.

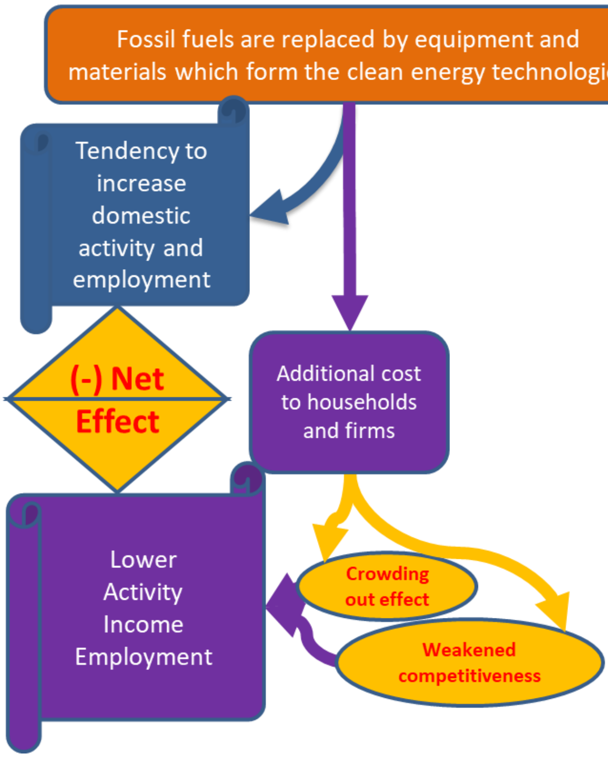


Figure 5a: The macroeconomic effects of decarbonisation without endogenous technical change
Source: Panagiotis Fragkos, Leonidas Paroussos, Pantelis Capros, E3Modelling, Athens

In contrast, Figure 5b shows the situation when endogenous technical change is considered. The effects noted above are still present, but in this case the dynamics of technology, and network, learning and scale effects lower the costs of low-carbon technologies over time, and may create completely new industries, that feed into new markets at home and abroad and strengthen industrial competitiveness[8]. The effect is to reduce the price effects on households and firms (and the low-carbon technologies may over time become cheaper than fossil-fuel technologies),

[7] Note that this is not always the case. For example, Turner et al. (2018) found that deployment and use of low carbon technologies involving stronger domestic content (supply chain activity) could offset costs and generate net positive gains. Specifically, the deployment of electric vehicles and fuelling with electricity triggered stronger wider-economy impacts than petrol/diesel, resulting from a lower import intensity and stronger domestic supply chain, in turn resulting in increases in household spending funded by more employment etc.
Reference: Turner, K. et al., 2018. 'Framing policy on low emissions vehicles in terms of economic gains: Might the most straightforward gain be delivered by supply chain activity to support refuelling?', *Energy Policy*, https://www.sciencedirect.com/science/article/pii/S0301421518303033?_rdoc=1&_fmt=high&_origin=gateway&_docanchor=&md5=b8429449ccfc9c30159a5f9aeaa92ffb
[8] See Aghion et al. 2015 http://www.lse.ac.uk/GranthamInstitute/publication/path-dependence-innovation-and-the-economics-of-climate-change/

mitigating or avoiding crowding out and weakened competitiveness. In this case, the net effect on GDP is ambiguous, and depends on such factors as the model structure, assumptions about crowding out and whether the economy is at full employment, and the policies through which the low-carbon technologies have been deployed in the model. Annex 4 shows the results of two model simulations from different models, one of which shows a positive effect of decarbonisation on GDP, and the other a negative effect. The headline message of both these results, however, is that the GDP impact of the modelled decarbonisation is small.

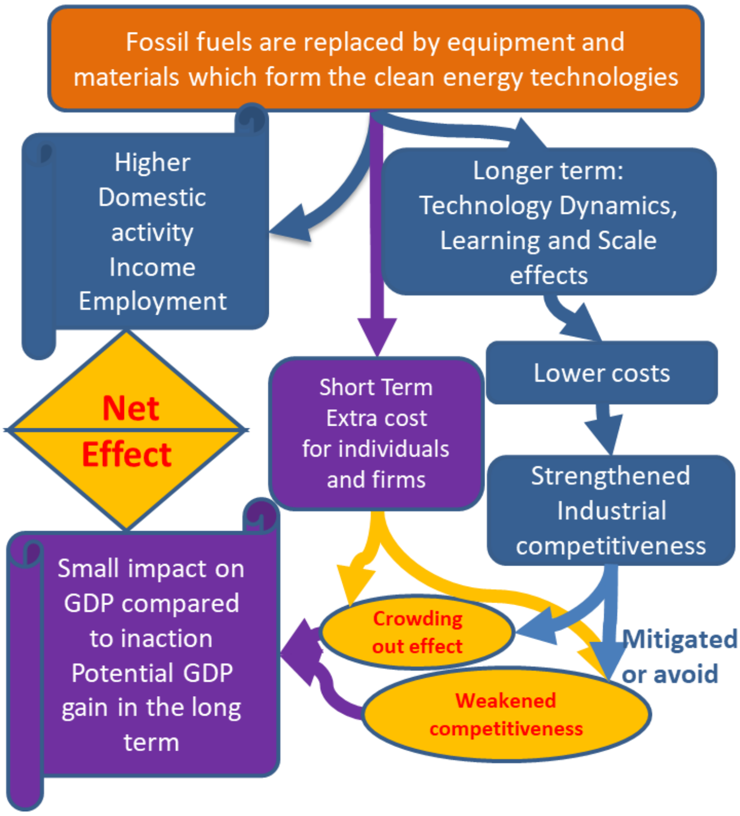


Figure 5b: The macroeconomic effects of decarbonisation with endogenous technical change
Source: Panagiotis Fragkos, Leonidas Paroussos, Pantelis Capros, E3Modelling, Athens

A further consideration relates to evidence that suggests the potential spillovers from low-carbon innovation to other sectors that drive GDP may be higher than for higher-carbon sectors. For example, using data on 1 million patents and 3 million citations, Dechezleprêtre, Martin and Mohnen (2013)[9] suggest that spillovers from low-carbon innovation are over 40 percent greater than from conventional technologies (in the energy production and transportation sectors). These effects, plus the cost savings as new networks and institutions are established, explain why Acemoglu et al. (2012)[10] make a powerful theoretical case to suggest that policy to support clean innovation can be temporary, because once it has become established it can be more innovative and productive than the conventional alternative.

[9] http://www.lse.ac.uk/GranthamInstitute/publication/knowledge-spillovers-from-clean-and-dirty-technologies-a-patent-citation-analysis-working-paper-135/
[10] Acemoglu, D., Aghion, P., Bursztyn L.and Hémous, D. 2012. 'The Environment and Directed Technical Change.' *American Economic Review*, Vol.102, pp.131– 66

It may be worth clarifying the precise meaning of the statement that the GDP impact of decarbonisation is likely to be small. UK GDP in 2018 was around £2.1 trillion (10^{12}). Real GDP growth in 2018 was around 1.4%. As an approximate illustration, if that growth rate were to continue through to 2050, UK GDP would be around £3.4 trillion at today's prices, i.e. on average UK citizens (ignoring immigration, population growth and changes in asset accumulation for simplicity) would be 62% better off than they are today. Then suppose that 'net zero' costs 1% of GDP (the Annex 4 GEME3-FIT model result suggests that the net cost of a 2°C target would be 0.8% GDP – the E3ME model shows a 3.4% gain). In absolute terms, the loss is £34 billion. With the UK economy continuing to grow at 1.4% per year, what this means is that under 'net zero' UK citizens would need to wait until half way through September 2051 to reach the level of income they would otherwise have achieved at the end of 2050. To enable the UK to play its full role in addressing climate change, to this author this cost seems small. Moreover, as is well known, GDP per capita is a very imperfect measure of quality of life and the net costs do not consider other benefits such as the improved health, well-being and happiness from better air quality and reduced loss of biodiversity.

As with any economic change there is likely to be some impact of UK decarbonisation on the fiscal position of the country. The most important influence on the fiscal position will be the impact of decarbonisation on GDP. It may also be the case that the low-carbon transition has been brought about through a shift in taxation from labour to carbon, and this may also have a (probably positive) effect on income and employment. And obviously where taxing fossil fuels (such as motor fuels in the UK) provides a significant source of revenue already, the shift away from them and any other carbon-based fuels that may have been taxed in the meantime will require, in the medium and long term, a new tax base to be developed. But these fiscal changes are likely to be gradual and manageable.

7. Financing costs of deep decarbonisation

The precise investment needs of getting to net zero by the middle of the century are unknowable, because they will depend on the cost dynamics of the different technologies involved and, as has been seen in section 4, these could change dramatically over the timescale concerned.

However, two things are clear: that very large investments will be required in low-carbon technologies and infrastructure; and that current levels of such investment are much too low.

There are estimates of the required order of magnitude of such investments. The Green Finance Task Force has totalled the Committee on Climate Change's estimates of the necessary investments in infrastructure to meet the fifth carbon budget (spanning 2028-32) as being approximately 1% of GDP (£22 billion) per year, of which public investment would be about £2.2 billion[11]. Much of this would be a redirection of, rather than additional, investment. It includes investments in: electricity generation (renewables, nuclear and carbon capture and storage), transmission and distribution networks, and smart grids, including storage; heat delivery (electric heat pumps, district heating

[11] Green Finance Taskforce 2018 *Accelerating Green Finance*, March, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/703816/green-finance-taskforce-accelerating-green-finance-report.pdf ; Committee on Climate Change 2017 'The infrastructure needs of a low-carbon economy prepared for climate change', Briefing Note, March, https://www.theccc.org.uk/publication/briefing-note-the-infrastructure-needs-of-a-low-carbon-economy-prepared-for-climate-change/

networks or possibly hydrogen-fuelled boilers) to energy-efficient buildings; electric vehicles, using batteries or hydrogen fuel cells, with the associated recharging and refuelling infrastructure, and active and public transport infrastructure; and carbon capture and storage (CCS). Longer term (e.g. from the mid-2030s) CCS may also be needed as a route to greenhouse gas removals – removing CO_2 from the atmosphere and storing it permanently. Transport and storage infrastructure (e.g. a network of CO_2 pipelines) is likely to require strong public sector involvement at least initially (e.g. grant funding or development as a regulated asset base – i.e. the return on investment is guaranteed by the regulator).

If the private sector is to contribute to these investments, and there is no way that these levels of investment will be reached without substantial private sector involvement, then the investments will need to comply with normal private sector risk-return criteria, which many of them are at present very far from doing.

A whole range of market and institutional arrangements, of which finance comprises one, but only one, stream (see Figure 6), have to be in place for technologies to reach wide diffusion. The risks encountered by and the return on the financial investments envisaged by the financing stream in Figure 6 will crucially depend on the existence and functionality of these arrangements, most of which will need to be legislated or otherwise enabled by government. Recommendations on these arrangements, which go well beyond the scope of this report, may be found in the report of the EU High-Level Panel on Sustainable Finance[12].

On the risk side of the investment equation are climate risk (changes in climate or weather may damage the investment or its return), litigation risk (companies may be sued if they are perceived to be knowingly causing climate damages), policy risk (policy changes and uncertainty may undermine the investment return), technology risk (the technology may not perform as envisaged) and construction risk (the return on investment may be compromised by delays or cost-over-runs). The private sector is used to estimating and factoring into its return estimates of both technology and construction risks. There are also risks to the financial system from a disorderly transition to a low- or zero-carbon economy. The report of the Task Force on Climate-Related Disclosure[13] has emphasised the importance of companies adequately assessing climate risks. Institutions with over $100 trillion of assets under management support Task Force for Climate Related Disclosure recommendations. And the Bank of England has looked at the impact on the banking sector.[14]

On litigation risk, New York State recently filed law suits against oil companies including Exxon Mobil for a "longstanding fraudulent scheme" to deceive investors and analysts. Cities and counties in New York, California, Colorado, Washington and Maine have filed civil lawsuits against oil and gas companies. Investors are likely to think twice about supporting companies that are exposed to these kinds of risks.

[12] See https://ec.europa.eu/info/sites/info/files/180131-sustainable-finance-final-report_en.pdf
[13] See http://www.fsb.org/work-of-the-fsb/policy-development/additional-policy-areas/climate-related-financial-disclosures/
[14] See https://www.bankofengland.co.uk/-/media/boe/files/prudential-regulation/report/transition-in-thinking-the-impact-of-climate-change-on-the-uk-banking-sector.pdf?la=en&hash=A0C99529978C94AC8E1C6B4CE1EECD8C05CBF40D

This leaves policy risk, the area that is most within the control of government, but the area in which also many governments, including the UK Government, leave the most to be desired. This is one of the subjects discussed in section 10 of this report.

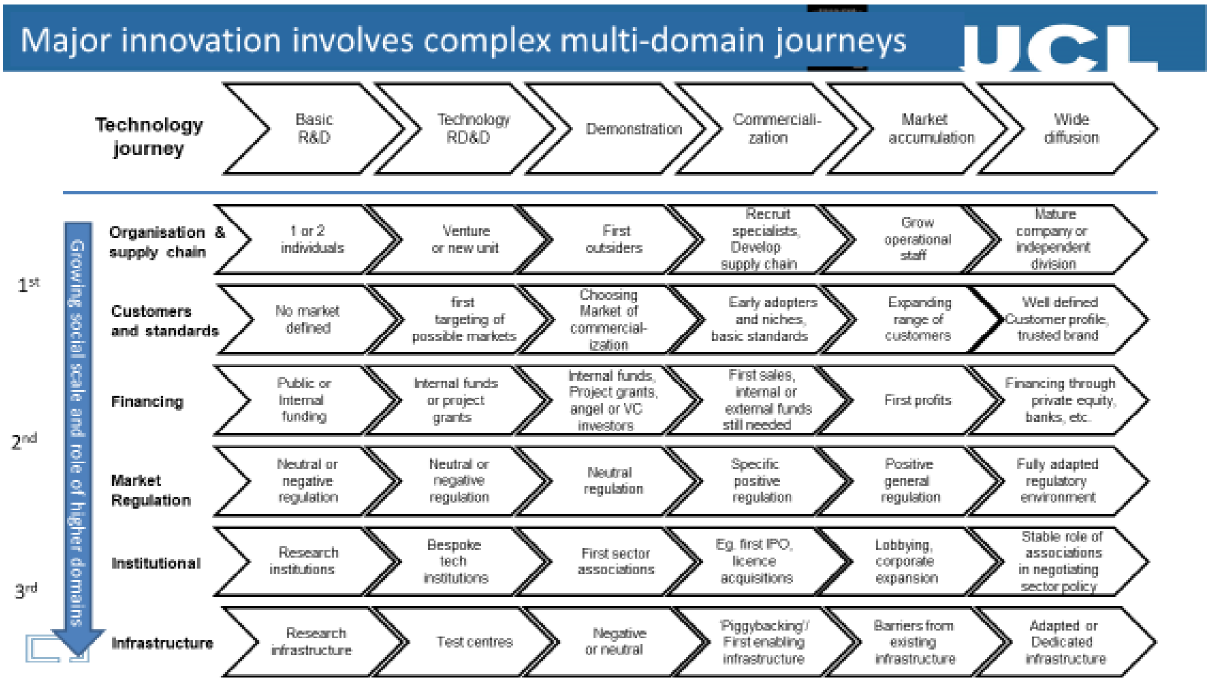


Figure 6: Necessary arrangements for the wide diffusion of new technologies
Source: Grubb, M., McDowall, W. and Drummond, P. 2017 'On order and complexity in innovation systems', *Energy Research & Social Science*, Vol. 33 pp. 21-34. Grubb, M. et al (2014) *Planetary Economics* 10.1016/j.erss.2017.09.016; derived from Fig.9.8 in Grubb, M., Hourcade, J.-C. and Neuhoff, K. 2014 *Planetary Economics: energy, climate change and the three domains of sustainable development*, Routledge, London/New York

On the return side of the equation, governments also have an important role to play. Many of the required investments are of high capital intensity and have relatively long payback periods. The regulatory environment can play a key role in determining the returns to these investments. But often regulations are only over short-time horizons relative to the returns on the investments and are subject to change as government policy shifts. This regulatory risk adds to the uncertainty over the returns to investment in renewables and other technologies. Inevitably this increases the commercial risk of these investments, and the associated interest rates, which, given their capital intensity, can reduce their economic viability. Governments can reduce these risks through co-finance (as with the UK Green Investment Bank before it was sold to the private sector) or through long-term contracts (e.g. the Contracts for Difference that have been so successfully used for offshore wind).

Government can also use its balance sheet, e.g. to provide credit guarantees, to help lower private sector borrowing costs and secure financing. This is especially important in the case of novel technologies, markets, and business models such as for CO_2 abatement (e.g. for large scale deployment of CCS).[15] Other possible mechanisms are long-term purchase agreements for the investment products, such as are increasingly being entered into by companies for renewable power. The investments may require these kinds of arrangements to help developers manage risk even when the underlying technologies are competitive with the fossil-fuel alternatives, because of their high capital and low marginal costs.

Not all the low-carbon technologies that are required are yet competitive, and government has a crucial role in supporting their commercialisation so that they become attractive to private-sector investors. Again there is a rich history, in the UK elsewhere, of the kinds of policies that work, including feed-in-tariffs and renewable portfolio standards (such as the Renewables Obligation in the UK). This topic is returned to in section 10.

Further discussion about government's role in promoting sustainable finance may be found in Annex 5.

8. Co-benefits of deep decarbonisation

It is clear that full decarbonisation entails dramatic changes in the use of energy and the use of land, especially agriculture, to reduce to zero the GHG emissions from the sectors in Figure 4. These reductions in GHG emissions will be accompanied by a range of other effects. For example, reduced combustion of fossil fuels will reduce emissions of other air pollutants, with significant health benefits. If agricultural emissions are reduced by people reducing their over-consumption of red meat, these healthier diets will also yield health benefits. And health may also be improved if reduced vehicle use in urban areas leads to more active travel, better public transport, and more green space in cities.

Where such benefits occur as a result of GHG emission reduction, they are called 'co-benefits' of abatement, and it is important that they are taken into account in considering the overall costs and benefits of abatement.

Figure 7 illustrates the potential scale of these co-benefits. It is a marginal abatement benefit curve (a MAC curve with benefits instead of costs on the y-axis). The blue areas are exactly analogous to the MAC curve in Figure 2. They show that by 2030 over 15 $GtCO_2e$ could be abated through measures with positive benefits.

Figure 7 also shows, in the red areas, the co-benefits that are associated with these abatement options. It shows that for many of the technologies, the co-benefits are actually greater than the main (blue) benefits. Over 20 $GtCO_2e$ can be abated through technologies with net benefits if these red areas are taken into account. Moreover, it can further be seen that the co-benefits considerably reduce the costs associated with the higher-cost technologies (the blue areas below the zero-cost line). Finally, Figure 7 also shows that the overall benefits (the areas under the positive red and blue bars) are very much larger than the residual costs (the blue areas below the zero-cost line). It was this kind of analysis that caused the Global Commission on the Economy and Climate to conclude (*op. cit.* p.45): "In the best circumstances, with early, broad and ambitious implementation, with rapid learning and sharing of best practice, these reforms and actions (in respect of cities, land use,

[15] The UK government used this approach to help finance the Thames Tideway sewer (which was too big a project to be just based on Thames Water's balance sheet)

energy, short-lived climate forcers, and manufacturing and service innovations - PE) could achieve as much as 24 Gt of emissions reductions (by 2030), or 90% of what is needed for a 2°C path. That, in turn, would require decisive policy change and leadership, combined with strong international cooperation, particularly to support developing countries' efforts. These actions would deliver multiple economic and social benefits. As a result, governments have good economic reasons to implement these actions even without accounting for their climate change benefits."

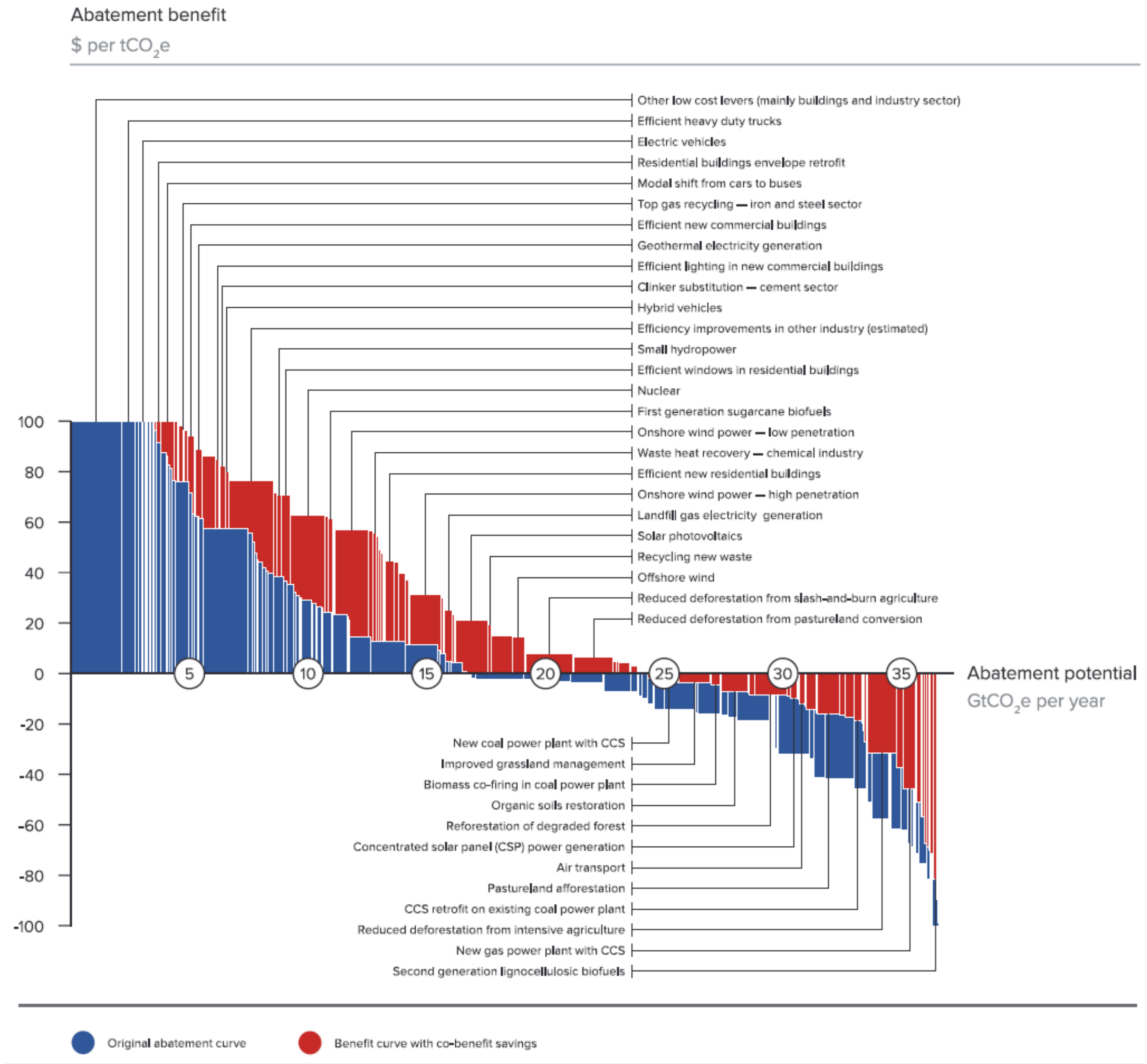


Figure 7: Marginal abatement benefit curve for carbon emissions reduction for 2030
Source: NCE (New Climate Economy) 2014 *Better Growth, Better Climate: the New Climate Economy Report*, The Global Report, The Global Commission on the Economy and Climate, Figure 6, p.43, https://newclimateeconomy.report/2014/wp-content/uploads/sites/2/2014/08/NCE-Global-Report_web.pdf

Figure 7 comprises global estimates. Many of the largest co-benefits will be in developing countries, which suffer from the worst air pollution. The UK co-benefits will be correspondingly less. But they are still substantial (the majority report of the Government's Committee on the Medical Effects of

Air Pollutants (COMEAP) [16] estimated in 2018 that "the range of central estimates of the mortality burden of long-term exposure to the air pollution mixture in 2013 in the UK was an effect equivalent to 28,000 to 36,000 deaths at typical ages, associated with a loss of 328,000 – 416,000 life years, when effects down to zero concentration were included." (p.x))

9. Transitional costs of deep decarbonisation

Even though the macroeconomic change from 'net zero' is likely to be small, the required structural change to the UK economy would be very great. Whole new economic sectors would be created, and a number of currently important economic sectors (most obviously oil and gas, but also everything to do with petrol and diesel internal combustion engines in vehicles). The new sectors would be likely to require different skills to the old, meaning that those workers in the latter would need to be re-trained if they were to continue in employment. These structural changes due to decarbonisation would come on top of those already expected from artificial intelligence, automation and digitalisation, providing a further rationale for extensive skills development and redeployment programmes. The success of government in facilitating such a shift will greatly affect the negative disruption felt by workers due to the low-carbon transition and therefore its political acceptability.

Another transitional issue will be the effect of decarbonisation on prices, and particularly on energy prices, until such time as infrastructure for low-carbon energy across electricity, heat and transport is fully built and operational. There is no reason to believe that ultimately low-carbon electricity, heat or vehicles will be more expensive than their fossil fuel counterparts (especially if the latter were to pay their full environmental costs), but getting to that point will require substantial development and deployment of these new low-carbon technologies and associated infrastructures, and over this period, depending on how these technologies and infrastructure and financed, energy prices may need to rise to pay for this.

It is well known that energy price rises in themselves are regressive. It is also well known that, with adequate offsetting measures from policy, they do not need to be so. Most important among these offsetting policies are measures to increase the energy efficiency of low-income households. The UK has a patchy record in the roll out of such measures, which will have to improve significantly if issues of fuel poverty are to be adequately addressed as decarbonisation gathers pace. This is true even for the current 80% emissions reduction target for 2050 to be achieved without increasing fuel poverty. It is even more true for 'net zero'. Again the government's commitment to and success in addressing this issue will be critical for the political acceptability of 'net zero'.

For further discussion of the issues around 'a just transition', see Annex 5.

10. Policy dependence of mitigation costs

It is clear that getting to 'net zero' will require transformative social and economic changes in practically every aspect of society, particularly in how energy is produced and used, what people eat

[16] COMEAP 2018 'Associations of long-term average concentrations of nitrogen dioxide with mortality', https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/734799/COMEAP_NO2_Report.pdf

and how it is produced, and how people travel. Figure 7 shows the role of policy in bringing about these changes.

Figure 7a illustrates the basic motivators of change: individual preferences for the present and expectations about the future; businesses' role in creating private value; and governments' commitment to the public good. The low-carbon transition will not occur without fundamental changes in each of these motivators.

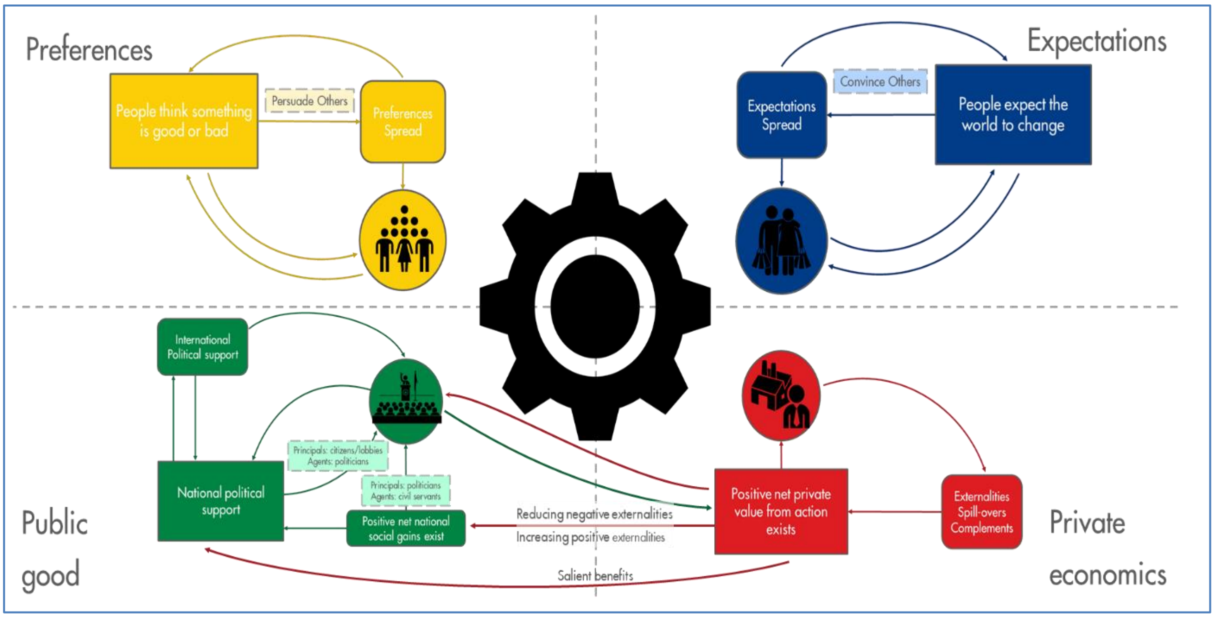


Figure 7a: Motivators of social change
Source: Annex 7, this report

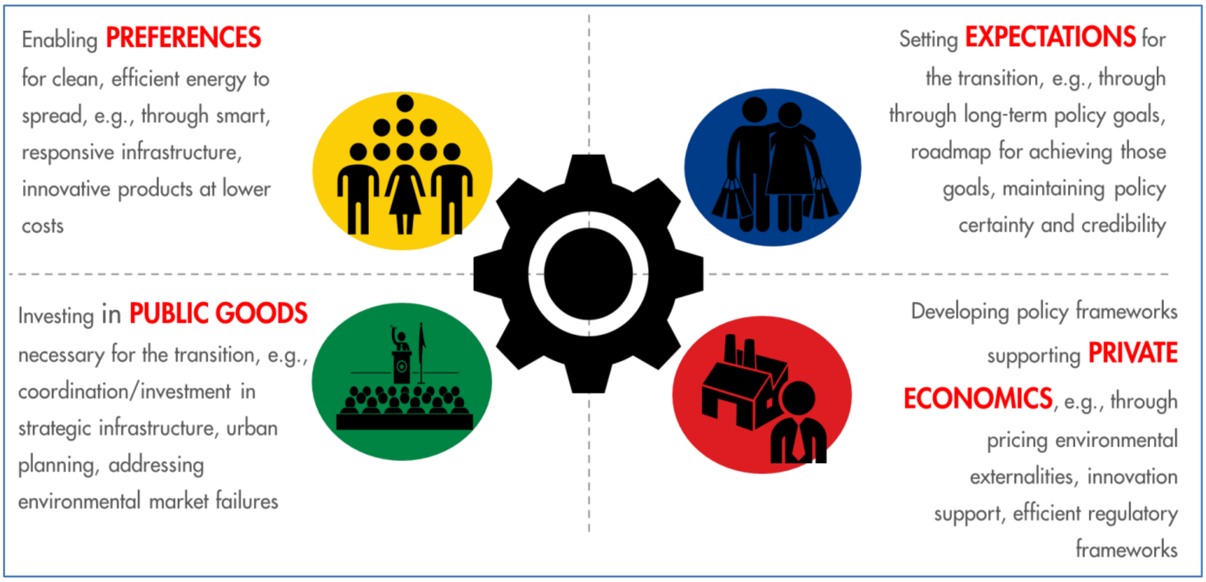


Figure 7b: The role of policy in engaging the motivators of social change
Source: Annex 7, this report

Public policy has a crucial role in bringing about these changes, as shown in Figure 7b. By investing in public goods and strategic infrastructure, especially in the current low-interest rate environment, and supporting the private economics of carbon emission reduction, it can greatly reduce the costs associated with decarbonisation. This, and paying attention to the need for a just transition, will change both individual preferences and expectations about the future. This is turn will encourage businesses to invest for that future, accelerating the deployment and take-up of low-carbon technologies in a context where the now-existing infrastructure enables them to be utilised to best effect. This reduces the cost of capital for these technologies, and therefore their overall costs still further, reinforcing the change in individual preferences and driving the transition still faster. The dynamics of this virtuous cycle are described further in Annex 7. The driving cog of public policy is now turning, but nothing like fast enough for ‘net zero’ by 2050.

The costs of the low-carbon transition are critically dependent on the quality as well as the stringency of public policy. Annex 8 lists the key principles of good public policy for decarbonisation as long-term clarity on the regulatory landscape, prioritisation of the role of markets, and policy processes that are transparent, predictable, and based on cost-benefit analysis. These principles are regarded as particularly important for policies relating to decarbonisation which, as noted earlier in this section, “typically require long-term action, significant investment from the private sector, and business and government supporting change in consumer behaviours”. If policy is successfully to drive the kinds of changes illustrated in Figure 7b, it will also need to be credible (actors must believe the government means what it says), consistent across time and governments, and across different policy sectors, and yet adaptive to new circumstances. Given the important role of expectations in stimulating investment and moulding behaviour (see Annex 3 and Figure 7) it is imperative that businesses and people are convinced that government is serious and determined about any ‘net zero’ target that it may adopt. By offering risk guarantees or subsidised loans, the government signals that it has long-term skin-in-the-game governed by its own policies thus underwriting some of the policy risk and sending a credible signal to private sector investors that the government is serious in seeing through its policy commitment.

Annex 8 gives a number of examples of where the UK Government has adopted policies in line with these principles, and a number where it has not. Three particularly egregious examples of the latter have been the cancellation of the Zero Carbon Homes policy when it was nine years into a proposed ten-year preparation period; the dramatic cut-back in energy efficiency measures for the existing housing stock; and the stop-go nature in recent years of the support for household solar photovoltaics, which has decimated what was a fast-growing, labour-intensive sector that had huge potential to connect people more directly to their energy use and awareness of the need for decarbonisation. It will take years to undo the scepticism that is now likely to greet further government policies in these areas – and that will all add to the cost of achieving the 80% reduction target, let alone ‘net zero’.

11. Conclusion and advice to the Committee on Climate Change (CCC)

Our advice to the Committee on Climate Change may be divided into three groups of thoughts

Costs and benefits of climate action generally

Both the costs and benefits of deep decarbonisation are unknowable with any precision. They depend too fundamentally on deeply uncertain outcomes, such as the damages from climate change in the long term, and the evolution of the costs of low-carbon technology over several decades. The very word 'costs' to describe decarbonisation expenditures is somewhat misleading, because in a very real sense such expenditures are also investments – both in new industrial activities, and in achieving the benefits of a stable climate. What is important is that the specifics of the investments, and the policies that incentivise them, deliver the best possible economic, societal and environmental returns.

One of the most remarkable features of the last decade has been the speed with which renewable and some other energy technology costs have fallen. This has taken most actors by surprise, rendering earlier economic forecasts of the costs of decarbonisation excessively pessimistic. Yet although the costs of specific technologies were arguably hard to forecast, the processes behind these falls, associated with learning by doing and new network economies, have long been known and remain predictable. What is clear is that both globally and for the UK in isolation, the cost of decarbonisation in decades to come will be a function of the action and investment taken today. The correct answer to the question 'what will it cost?' is therefore what economists call endogenous; it depends on what is done now. This is an important policy message. If we work with the investment replacement cycle and avoid locking into high-carbon inefficient infrastructure as old kit is retired, we can avoid the need to replace and retrofit the investments prematurely. At the same time, this will provide a credible signal to innovators and investors to develop and deploy new networks of connected, resource-efficient renewable technologies, inducing further cost reductions while keeping potential benefits high.

The evidence from UK and global decarbonisation so far backs this contention. In addition to the cost reductions seen in key low-carbon technologies, there has been no appreciable difference in rates of economic growth between those countries that have reduced emissions substantially and those that have not and yet the former camp are arguably in a stronger position to benefit from a global transition to a zero carbon economy in years to come.[17] Moreover, economies which have integrated decarbonisation into other policy aims will have generated growth, for example by improving energy efficiency, reducing productivity losses from particulate pollution and congestion and attracting skilled workers to cleaner, more sustainable and technologically advanced cities. The potential magnitude of these benefits should not be underestimated.

This all suggests that the macroeconomic costs of investing in deep decarbonisation are likely to be relatively small in the context of a growing economy. With innovation and technical progress, and growing markets in other decarbonising countries, there could be net benefits from deep decarbonisation over coming decades throughout the transition. For a medium-sized open economy like the UK, early action and a clear policy steer can help foster a comparative advantage in one of the world's fastest growing markets. Given the potentially very large damages from unabated

[17] A similar story applies to business. Share prices for renewable goods and services have outperformed those of carbon-intensive sectors worldwide, reflecting the growing risk investors attach to asset stranding and devaluation.

climate change, and the perhaps small (but not negligible) existential risk of such change, we conclude that strong mitigation action is far preferable to not acting.

To be more specific about technologies, we note that technology cost reductions through innovation and deployment in respect of, for example, offshore wind, have meant that the costs of mitigation using this technology are much less than were previously thought likely. We see no reason to believe that such cost reductions will not be seen for other key technologies, such as batteries, fuel cells, electric vehicles and a range of other low-carbon technologies. However, these cost reductions will depend on mass deployment of these technologies, and not just on research and development. Government must stand ready to incentivise this deployment, especially in the early days of technological roll out, and to put in place the necessary infrastructure.

The combustion of fossil fuels is associated with a number of negative effects on the environment and human health, as well as with GHG emissions. In consideration of the costs and benefits of GHG emission reduction, it is important to factor in the non-GHG benefits, such as reduced local air pollution. In the short term the benefits from the reduction of these other air pollutants are likely to outweigh the climate benefits of GHG reduction.

The macroeconomic costs of deep decarbonisation may be small (or, indeed, negative for a fossil fuel importing country like the UK), but the structural changes underlying these aggregate costs will be very large. The beneficiaries from the structural changes are unlikely to the same as the losers. The transition through these structural changes will need careful handling if they are to be politically acceptable. Re-training programmes, energy efficiency measures and compensation schemes for low-income and otherwise vulnerable people will need to be put in place to help people and businesses to adjust to the decline of some sectors as others are growing to take their place, and to potential short-term increases in energy prices. The UK Industrial Strategy focus on developing strong domestic supply chains needs to be extended and integrated to support the full spectrum of decarbonisation actions. While this may mean higher short-term costs relative to importing the intermediate goods and services required for such actions, the economic and employment benefits of creating sustainable supply chains for decarbonisation are key to public acceptability and laying the foundations for a ‘just transition’.

It is important to realise that the costs of deep decarbonisation depend to a large extent on the actions that attempt to achieve it. Policies that create the expectation of deep decarbonisation, and that put in place measures to achieve it that are aligned with investment cycles, and therefore prevent stranded assets and early capital write-offs, and that ensure that the infrastructures are in place to support private investment in low-carbon technologies (e.g. in electric vehicles), and behaviour changes of individuals and communities (e.g. towards more walking and cycling in cities) will be very much cheaper than those that do not. Early action that prepares businesses and citizens for these changes and enables them to adapt to them over time, is likely to be cheaper that inaction now necessitating a crash policy programme to meet the targets later.

Static cost-benefit analysis (CBA), as exemplified by an approach that seeks to work incrementally up a putative MAC curve, is simply unable effectively to capture these dynamic effects, which may confidently be expected to reduce the costs of many of the MAC curve technologies that now seem expensive. This, combined with the uncertainties, irreversibility and potential tipping points in the climate response to GHG emissions, with their non-negligible risk of very large costs indeed, means that classical CBA is singularly unsuited for assessing the costs and benefits in this case, which is why we have not sought to use it for this report.

Specific case of 'net-zero' versus 80%

The 80% target allowed some scope for continuing emissions from hard-to-decarbonise sectors. 'Net zero' allows much less. Under 'net zero' all sectors need to decarbonise (or their emissions must be offset by removing an equivalent amount of emissions from the atmosphere, at considerable expected cost). One advantage of this is that it removes uncertainty and the temptation of sectors to lobby for a larger share of the remaining 20% of emissions. The clarity of a 'net zero' goal, coupled with good policy design, could help stimulate innovation across all sectors, and cut the cost of capital, thereby bringing down the overall cost of mitigation.

While it may be the case that 'net zero' will cost more than an 80% reduction, the arguments in the previous section still stand: there are no grounds for thinking that it will have a significant impact on economic growth, provided that policy is in accordance with the principles outlined above. Moreover, the dynamics of endogenous innovation (see Annex 3) suggest that starting early with a target of net zero may deliver lower costs than aiming for an 80% reduction (noting that the costs of mitigation have already fallen much faster than expected as a direct result of more rapid than expected deployment). Finally, there are credible scenarios to meet a 'net zero' target, it will take time to put new infrastructure in place and allow the capital stock to turn over without extensive early write-offs of plant and equipment, some of which is long-lived. This argues against adopting too early a date to achieve 'net zero'.

In addition, while there are economic advantages of being among the global leaders in decarbonisation, there are risks of being too far ahead of the pack. It is a finely balanced matter of judgement of where to draw this line, but with the Industrial Strategy the UK Government does at least have a policy orientation that enables it to exercise judgement on such matters. There is a greater risk, when the rest of the world is decarbonising, in being a last rather than a first mover. We therefore conclude that the date for a 'net zero' target should be 2050.[18]

There may be a temptation to think that the last 20% of emission reduction is likely to be too expensive to justify the ambition of limiting the average global temperature increase to 1.5^{o}C as opposed to 2^{o}C, even if it turns out to be less expensive than current technologies may lead us to expect. We think that such as view is not justified by a reading of the IPCC 1.5^{o}C report, which makes it clear that the avoided damages from the lower temperature increase could be very large indeed We further think that the UK is well placed to be among the economies most likely to benefit from a transition to 'net zero', provided that policy clearly and consistently indicates that this is the 2050 objective, and policy on the way is consistent with that objective. Overall, therefore, cost-benefit considerations lead us to the conclusion that mitigation action to achieve 'net zero' by 2050 is fully justified.

[18] Sweden has taken a similar approach, with a target to use no fossil fuels by 2045.

Reflections on the CCC's approach to assessing the costs and benefits of 'net zero'

We conclude that the CCC has approached the issue of assessing the costs and benefits of climate change in a robust and realistic way. It makes sense to consider the resource costs of deep decarbonisation using MAC curves, with conservative expectations of future costs (noting, as above, that these costs have in the past been systematically overestimated and that the costs will be a function of supportive decisions and action taken today), and to compare the resource costs of 'net zero' with those of an 80% reduction, rather than some hypothetical 'no action' scenario, which has long since ceased to exist.

However, it is very important not to confuse resource costs with GDP impacts. Macro-modelling is required to generate GDP impacts. Many examples of such modelling exist, and it is not clear that the CCC could have materially improved the evidence base by carrying out further modelling of this kind. A reasonable conclusion from the macro-modelling that exists in this area is that the GDP costs of 'net zero', compared with an 80% reduction target, are likely to be small – less than one year's GDP growth – and could even be positive. It is worth repetition that having a clear, long-term policy framework and roadmaps across sectors will be vital in minimising or eliminating these costs and maximising the opportunities. However, it is important to be aware and take account of transitional costs and benefits, and, in particular, to ensure that low-income and otherwise vulnerable households are not adversely affected by the structural and price changes that are likely to occur during the transition.

It is also important to take full account of the co-benefits of mitigation action – quantifying these in both physical and monetary terms where possible. Co-benefits such as reduced air pollution are likely disproportionately to favour low-income and vulnerable people, the former of whom tend to live in those areas worst affected by air pollution, and it is important that this is both analysed and communicated properly.

Finally, good policy design is vital to keeping costs low and maximising benefits. Such policy includes a stable long-term direction with clear governance, regular reviews for flexibility, use of markets to find the best solutions, support for large-scale deployment of new technologies as well as research and development, and approaches that are tailored to the needs of each sector, while maintaining consistency across the system.

ANNEXES

Note: All members of the Advisory Group served in their personal capacities, and affiliations are for identification only. In particular, their views may not represent those of their organisations.

ANNEX 1

Direct Resource Costs and GDP

Philip Summerton, Cambridge Econometrics

This brief note sets out why the direct resource cost is not the same as the GDP impact, as well as highlighting some of the issues to be aware of when using the direct resource cost.

As used by the CCC, the Direct Resource Cost is a measure intended to reflect the additional cost of all resources required to meet a carbon target over a given time period.

At a micro scale it is intuitive: if I decide to reduce my personal transport emissions and buy an electric car instead of a new petrol car, the direct resource cost would be the additional cost of the electric car, plus fuel and all running costs over the lifetime of the vehicle (appropriately discounted – for ***my*** preferences) compared to the cost of buying and running a petrol car.

At an economy-wide scale, it seems intuitive to aggregate all the measures that everyone within an economy needs to take and derive an economy-wide version of the Direct Resource Cost to the UK of meeting, say, carbon budgets. This is equivalent to adding up everything under the MAC curve for a given carbon budget.

It's a useful measure of the scale of the required changes, but it's worth noting it only shows ***net*** changes in cost which can mask the scale of the structural changes required.

The measure relies on 'good' projections of future costs/prices which are not only uncertain but also endogenous to the policy choices that are made. It also relies on an assumption for a discount rate to which the outcomes are very sensitive: in this type of analysis the short-term costs are well known, whereas the longer-term benefits accruing to society are more uncertain because they're more sensitive to long-term future conditions.

As a microeconomic measure of "welfare" loss that is aggregated, it does not represent the macroeconomic impact (GDP) unless the following conditions are met:

- full employment of resources (in the short and long run), including:
    - financial resources (money)
    - labour supply
- the economy assessed is closed to trade

If the economy in question trades (across borders), then the direct resource cost measure becomes less useful because it doesn't take account of the impact that a changing energy sector might have on the trade balance (and therefore GDP).

For example, if an economy manufactures electric cars, but imports petrol, then we could have the result that switching to electric cars leads to:

- a positive direct resource cost (implying a *reduction* in welfare): it's more expensive to have the electric car over the lifetime
- a positive GDP impact (implying an *increase* in welfare), the additional cost is outweighed by the change in the trade balance

Put simply, this happens because the direct resource cost measure ignores the fact than all costs are benefits (incomes) to someone else, whereas GDP (as a measure) accounts for this.

One feature of low carbon transitions is that they tend to require capital-intensive solutions, with the implication that there will need to be more investment in the short term compared to the high carbon alternative.

This investment will lead to crowding out if there is no spare capacity but, if there is spare capacity (unemployment, financial resources) the additional investment could lead to an increase in the level of GDP (eg through Keynesian dynamic multipliers, etc).

This would, again, lead to a difference between the direct resource cost and the GDP impact, the sign and scale of which is explored in Annex 4.

ANNEX 2

Achieving Net Zero Emissions

Mallika Ishwaran, Shell International

I. Global perspective

The Conference of Parties in Paris (COP21) in December 2015 saw an unprecedented 195 countries (including the European Union) agree to limit global temperatures to well below 2C, with countries contributing to the global effort to reduce greenhouse gas emissions as set out by their Nationally Determined Contributions. The Paris Agreement was ratified in November 2016, by at least 55 countries responsible for at least 55% of global emissions. Although the US has since indicated it is pulling out of the agreement, the recently concluded COP24 in Katowice was a significant step forward in operationalising the Paris Agreement by agreeing much of the 'rulebook' for its implementation.

However, there are fundamental economic, technological, social, and political uncertainties around pathways for achieving the ambition of the Paris Agreement, which a scenarios approach can help meaningfully explore and understand. Shell has been using this approach for almost 50 years, as a way of putting structure around fundamental uncertainties and systematically producing a range of possible and internally consistent futures. The latest scenario – **Sky**[19] – provides a technically and economically possible pathway to achieving global net zero emissions in time to meet the Paris ambition. The Sky Scenario has also been included in the IPCC 1.5C report among the relatively small number of credible pathways to limiting global temperature rise to 1.5C.[20]

The Sky Scenario is builds on Shell's previous New Lens Scenarios – Mountains and Oceans – combining features of both to deliver an energy transition at the pace required to meet the Paris ambition. It combines normative goal-seeking analysis with plausible build rates for future energy technologies and explicitly accounts for inertia in changing energy infrastructure. The six key elements of Sky are:

- Electrification of final energy, which is required to make the most of the potential of renewable technologies like solar and wind. In the Sky Scenario, the next 50 years sees the world moving from less than 20% to more than 50% of the entire economy electrified. This translates to a tripling of the pace of electrification compared to historical norms – from 2% points per decade since the 1960s to 6% points per decade going forward – and a growth in the size of the electricity sector by about a factor of five.
- Growth of new energy systems, which support decarbonisation of the end use of energy. Integrating an increasing share of renewables into the electricity system and electrifying end use of energy in industry, transport, and buildings as much as possible is an essential ingredient of Sky. In addition, shifting to lower carbon molecules in hard-to-electrify sectors is also required, such as replacing oil with biofuels in aviation and replacing natural gas with hydrogen for heating. New energy sources grow up to fifty-fold, with primary energy from renewables eclipsing fossil fuels in the 2050s.

[19] https://www.shell.com/energy-and-innovation/the-energy-future/scenarios/shell-scenario-sky.html

[20] It is classified 'a delayed action pathway relative to others', because emissions don't show a clear downward trend until the late 2020s but the transition proceeds rapidly after that.

- Structural energy efficiency improvements, which minimise rebound effects and lead to gains above historical trends. In developed regions like the UK, energy use does not grow due to a combination of changing socio-economic norms and rising energy efficiency, and it therefore decouples from economic growth. In the developing world, global final energy continues to grow, driven by growing populations and rising household incomes. However, this is moderated not just by more efficient production processes but more crucially by energy efficient infrastructure. For example, in having urban forms which are compact with integrated wastewater, power, and energy systems.
- Carbon capture and storage (CCS), which is a critical technology to mitigate emissions from harder-to-abate sectors. For example, carbon capture and storage on industrial facilities that continue to require thermal fuels, such as iron and steel and cement[21], or to reduce emissions from hydrogen production (which in turn provides energy for industry, power, heating or transport). Alternatively, carbon capture and storage with bioenergy can create negative emissions to balance out emissions from sectors of the economy that are likely to continue to emit. Sky estimates some 10,000 large carbon capture and storage facilities are built, compared to fewer than 50 in operation in 2020.
- Robust and rising economy-wide carbon pricing mechanisms, either via explicit carbon taxes and trading schemes or implicit regulations and mandates. For society to meet the Paris goal, it will require system-wide change – of both energy supply and end use – and economy-wide mechanisms are required that put a value on avoiding emissions. Under the Sky Scenario, carbon pricing ratchets up significantly from today's levels to a median price of around \$200/tCO2e in a net-zero emissions world, and there is increased convergence across countries and regions in the level of implemented carbon price.
- Ending deforestation is crucial for achieving a <2C outcome, and significant reforestation is required to limit global temperature rise to 1.5C. Achieving the global balance called for under the Paris Agreement requires looking beyond energy use and looking at the interplay between the energy system and natural systems, such as through bioenergy. The Global Carbon Project estimates that land-use changes have resulted in 5 $GtCO_2$ per year being emitted for each of the last 20 years. Sky assumes significant land-related actions to bring the land-use and agricultural systems back into balance and ensure that net deforestation reaches zero. The Nature Conservancy estimates that around 500 $GtCO_2$ in total can be drawn down from the atmosphere at costs today below US\$100/tCO_2e and sustainably stored by improved soils and extended forest cover.

As a result, in Sky, oil demand peaks in the mid-2020s largely because of vehicle electrification, coal is assumed to have already peaked and is plateauing now, and natural gas begins to plateau in the 2030s as it is substituted out of power generation by renewables, and beyond that time begins its long-term decline. Thus, while the net zero emissions energy system is about twice the size of

[21] The production of Portland cement – the most commonly used cement in the world – also involves both high temperatures and the release of CO_2 as part of the underlying chemical process that occurs, for which CCS is also likely to be required to capture process emissions from cement.

today, the share of fossil fuels falls to 20% on average (from 80% today) with low and no carbon energy sources such as wind/solar, nuclear, and bioenergy accounting for the lion's share.[22]

While Sky provides a technologically and economically possible pathway to achieve the Paris goals, the social and political drivers are equally important. Mountains and Oceans are 'exploratory' scenarios exploring possible futures for the energy system, looking at the wider economic, political, social, and environmental drivers of change. Sky, on the other hand, is a 'normative' scenario specifically exploring *how* the Paris goals can be met and as such requires the best of the societal processes and drivers of change in both Mountains and Oceans to accelerate the pace of energy transition. For example, it requires the top-down policy leadership to create the necessary policy frameworks exemplified in Mountains and the bottom-up business innovation and change in consumer cultural norms exemplified in Oceans.

Overall, achieving the ambition of the Paris Agreement at the global level will require accelerating the current pace of action. Individual countries' current Nationally Determined Contributions don't put the world on a <2C trajectory. Accelerating action will require governments, businesses, and consumers working together to create a virtuous cycle of change. Governments need to provide the policy framework required to support the transition to low-carbon economies that can thrive on low-carbon energy, whether by implementing carbon pricing mechanisms, supporting R&D and commercialisation of new low carbon technology and by driving behaviour change in consumers. Once the appropriate policy frameworks are in place, businesses and markets can drive change in terms of innovation, development of new products, new ways of supplying and consuming energy, and new business models to support this. Finally, consumer preferences and choices towards low carbon products and services can provide the 'pull' to complement the 'push' through government policy and business innovation and new technologies. Achieving the Paris goal will require all three actors pulling in the same direction to achieve society's objective to reduce greenhouse gas emissions and address climate change.

II. UK context

The energy transition in Sky looks different and moves at different paces in different countries and regions. In the UK, progress in the energy transition has been dominated by the power sector, through policy support and frameworks to commercialise and integrate an increasing share of renewables into the electricity system. Based on the six Sky building blocks, there are areas where further progress needs to be made if the UK is to achieve net zero emission by 2050.

- Mobility: In Sky, no new internal combustion engine cars are sold in the UK after 2030. However, despite policy announcements in this area, Sky and other UK-specific scenarios work support the view that more ambition is needed on passenger vehicle decarbonisation, particularly in developing charging infrastructure to support greater uptake of passenger and light duty electric vehicles if the UK is to meet its legislated targets. For heavy duty vehicles, aviation and shipping, a significant step-up in action is required to develop, commercialise, and deploy new drive trains and fuels, such as biofuels and hydrogen.

[22] It is worth bearing in mind that despite fossil fuels share falling, ongoing investment in fossil fuels will be required to meet demand through the transition. In Sky, the world will still need 85% of today's oil and gas production mid-century, dropping to 30-40% by the end of the century.

- Heat: The UK's heat network is dominated by gas and achieving net zero emissions will require policy action starting now. A range of solutions are likely to be required, responding to local conditions and consumer preferences. For example, alongside efforts to improve energy efficiency, there are potential roles for hydrogen, heat pumps (including hybrids) and district heating.
- CCS and bioenergy: There is an important role for negative emissions through CCS and bioenergy in the UK, to mitigate harder-to-abate emissions from passenger aviation and freight transport (road, rail, air, ship) as well as a critical technology for reducing industrial emissions and emissions from hydrogen production. Both imported and domestic bioenergy are required to achieve net zero emissions, primarily to create negative emissions in combination with generating power, hydrogen or industrial heat.
- Domestic and international offsets: While Sky achieves a well below 2C world by bringing deforestation to an end, getting to 1.5C requires significant reforestation. Nature-based solutions such as forestry offsets provide a cost-effective mechanism to mitigate the most technologically difficult or economically expensive emissions to eliminate, with potentially significant albeit limited role for domestic (such as through peat, forestry) and international (through the Article 6 rule book) offsets.
- Carbon pricing policies: Driving economy-wide change to net-zero will require a robust, predictable, and rising carbon price in the UK, to bolster market confidence, investment, skills that industry and society need to achieve net-zero emissions by 2050.

ANNEX 3

The Power of Innovation

Dimitri Zenghelis, London School of Economics

Summary

We are asked: what it will cost to deliver a net zero economy by 2050? The correct answer is that it is endogenous; it depends on the actions and decisions taken today. We cannot accurately predict the technologies, behaviours or institutions of the future. However, theory and evidence tell us that the costs of tackling climate change and promoting sustainability will be higher if we delay action or make the wrong investment decisions today. This background note argues that policymakers and economists should therefore pay less attention to predicting the future and more attention to directing it. Rather than act as a drag on growth, economics appropriately applied tells us that if we act quickly and clearly, a sustainable future could be cleaner, quieter, safer, more technologically advanced and more prosperous than the alternative.

The future, like the past, will be path dependent

The standard economic approach to predicting the future makes assumptions about future technologies, tastes and preferences and institutions and use them to impose long term structural solutions to their models. When looking two or three years ahead, this makes sense. The UK Treasury's economic model looks at the effects of perturbations in things like interest rates, policies and oil prices on output and inflation assuming the structure of the economy remains unchanged. But over the longer term, for example over decades, it is the structural assumptions that are the very things we care about forecasting. In order to credibly answer questions about the cost of decarbonisation, we want to know how technologies will emerge, how tastes and preferences change, what underlies a shift from one network to another and how do consumers change habits and social norms?

The answer to these questions depends primarily on innovation, not just in technologies but also in behaviours and institutions and innovation does not happen in a vacuum; innovation is a path dependent process. First, scientists work in areas that are well funded and where other good scientists work: research and knowledge production are path dependent. Second, deployment of innovations is path dependent: incentives to deploy innovations that leverage existing infrastructure are much higher than for potential new infrastructure (for example, conventional cars are easier to sell than electric vehicles because there are many more existing petrol stations than charging stations; smart meters require smart electric grids, and so on). Finally, incentives for technology adoption create path dependence because of the pervasive influence of networks: if the benefits of using a product rise with the number of others using it, unilaterally switching to an alternative may be unattractive.

These reasons imply that socioeconomic systems have strong inertia. Unsurprisingly, therefore, it is initially difficult to shift the innovation system from dirty to clean technologies without direct policy intervention. Moreover, ex ante predictions of the costs of such a shift are correspondingly biased when relying on backward looking data. But there is a more hopeful flip side. Once a critical mass or threshold of deployment is reached, these effects go the other way rapidly accelerating the positive and reinforcing feedbacks derived from reduced technology cost to further deployment and investment in supporting networks, infrastructure and institutions. Indeed, in the deployment and adoption of clean technologies, path dependence arises specifically because of powerful network effects and high switching costs. For example, once electric vehicle infrastructure is in place, the incentives to conduct research and development on electric cars will increase substantially relative to fuel cell or combustion engine vehicles. Path dependence also affects the effectiveness of public policies. For example, dense cities with integrated public transport require lower carbon taxes than sprawling cities in order to achieve the same reduction in emissions, because shifting the transport mode is easier. The key challenge for policymakers is to utilise this knowledge of path dependence to channel growth in the direction we want.

A key source of path dependence in socioeconomic systems is the presence of 'complementarities' in expectation formation, that is, when the payoff to the whole group from working together is greater than the sum of the payoffs of its parts. In particular, 'strategic complementarities' arise when agents make individual decisions that affect each other's welfare and one agent's greater productivity makes *all* the other agents more productive. Research and development externalities[23] and learning spillovers[24] in low-carbon technologies have these features – as more scientists start thinking about clean energy, more ideas and innovations emerge such that other scientists can 'stand on the shoulders of giants' and see further in the clean energy domain.[25] As technology costs fall, more businesses, consumers and politicians become aware of the opportunities associated with low carbon technologies and the policy environment at the national and global level becomes more favourably disposed to supporting decarbonisation. As noted below, most integrated assessment models rarely attempt to model this feature of research and development nor the effect of policy credibility on the formation of expectations. As a result, their power to inform policy is limited.

Can economists model the future?

As noted in the main text, conventional economic models plot a spectrum of low-carbon interventions ranging from low to high cost, in the form of a 'marginal abatement curve'. This starts with the proverbial 'low hanging fruit' of energy efficiency and waste reduction, moving steadily to more costly technologies in more marginal locations. The more ambitious the attempt to decarbonise the economy, the more expensive the investment that needs to be undertaken. As a result, economists routinely predict high costs associated with decarbonisation pathways sufficient to meet the Paris goal of 2-degree temperature rise relative to preindustrial times (even more so for 1.5 degrees). Yet this static approach notably fails to model the processes and dynamics that lead to systemic transformational innovation examined in the preceding paragraphs.

Although economic models increasingly apply the concept of learning by doing (this says that as you develop and deploy a new technology, you learn through experimentation how to fabricate, fit, engineer and maintain it driving innovation which makes goods cheaper and more productive) they fail to account for the drivers of deployment. In other words, even where they get the learning right, they fail to predict the doing and consequently overstate the cost of deploying new technologies.

The figure below shows forecast made by the International Energy Agency (IEA) for the deployment of renewables compared with actual outturns. The IEA is arguably the leading authority on energy

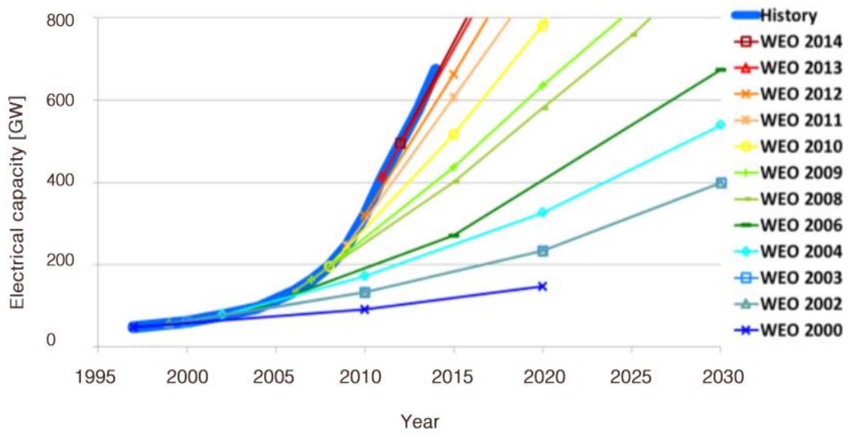
[23] See Romer, P. 1990. Endogenous technological change. Journal of Political Economy, 98(5), S71–S102, 1990; Aghion, P., and Howitt, P.W. 1992. A model of growth through creative destruction. Econometrica, 60(2), 323–51.

[24] Arrow, K.J. 1962. The economic implications of learning by doing. Review of Economic Studies, 29(3), 155–73.

[25] For example, using OECD patent data, Braun et al. (2010) find that both wind and solar technologies create knowledge spillovers at the national level. Many existing green technologies may also exhibit scale effects (Moore, 1959).

technologies, yet they systematically and repeatedly underestimate the deployment of renewables and correspondingly overestimate the costs.

IEA renewable capacity forecasts, excluding hydropower



Source: Metayer, M., Breyer, C. and Fell, H.-J. 2015 'The projections for the future and quality in the past of the World Energy Outlook for solar PV and other renewable energy technologies https://www.lut.fi/documents/10633/70751/The-projections-for-the-future-and-quality-in-the-past-of-the-World-Energy-Outlook-for-solar-PV-and-other-renewable-energy-technologies-EWG-WEO-Study-2015.pdf

What the IEA failed to account for is the broader social context, how governments subsidised new technologies when expensive, precipitating price falls such that others would deploy them. They failed to anticipate that once a technology becomes sufficiently competitive, it starts to change the entire environment in which it operates and interacts. New supply lines are formed, behaviours change, and new business lobbies push for more supportive policies. New institutions are created, and old ones repurposed. As costs fall and expectations of market size increase, additional investment is induced and the political and commercial barriers to a transition begin to drop away. A tipping point is eventually reached where incumbent technologies, products and networks become redundant. Incorporating these features of path-dependent phenomena – knowledge spillovers, network effects, switching costs, feedbacks, and complementarities – into economic models is difficult and often leads to a multiplicity of 'equilibria', which can often be Pareto-ranked.[26] Yet they are features of the real world which must be acknowledged.

The dynamics outlined above point to another conclusion. In a structural transition, those late to recognise the change stand exposed to stranded or devalued assets. Of course, such tipping points take time to emerge and in the meantime are delayed by the forces of inertia outlined above. This

[26] See: Krugman, P. 1991. History versus expectations. *Quarterly Journal of Economics*, **106**(2), 651–67; Matsuyama, K. 1991. Increasing returns, industrialization, and indeterminacy of equilibrium. Quarterly Journal of Economics, 106(2), 617–50. Predicting outcomes in the presence of equilibrium multiplicity is further compounded by the fact that innovation is inherently a stochastic process (Acemoglu and Zilibotti, 1997; Klette and Kortum, 2004).

makes the political economy of a transition vital to understand. Losers outplay winners by having greater access to politicians – they exist and know who they are and how much they stand to lose whereas potential winners are just that, potential, and in many cases widely distributed. At the same time, technology costs start high and new networks have yet to emerge so there is good politics of resisting change.

The evidence suggests the wrong approach has been applied

The evidence that economists using static models miss complex interactions and feedbacks is already clear to see. No model 'predicted' that, by now, renewables would be the biggest source of investment in global energy generation, outpacing coal, oil, gas, nuclear and hydro combined. No one predicted that the price of solar photovoltaic (PV) would fall 44% in the two years to the end of August 2017 and by 83% since 2010, a period over which the price of wind turbines dropped 35%. They did not predict that LED lighting would have gone from less than 5% of the global lighting market to more than 40% in the past six years, while plug-in vehicles in Norway alone have gone from around 5% of sales to nearly 50% and account for all the growth in China's car market.

Instead, the Intergovernmental Panel on Climate Change (IPCC) predicted that meeting a 2°C stabilisation target would cost an average loss in global output of 2.9 percent to 11.4 percent a year by 2100. Such spurious precision on costs is risible when economists struggle to predict GDP two years out to one decimal place, let alone over 80 years. It is important the CCC does not make the same mistake.

Mind over matter – how expectations and psychology shape the real world

To the extent that economists are believed, they become part of the problem. Getting the future wrong has the potential to make the future wrong (by generating what game theorists call an inferior Nash equilibrium). Economic theory indicates that the pathway selected will depend on the expectations of people about technologies as well as the initial conditions of the innovation process (Krugman, 1991; Cooper, 1999). Even if clean technologies were starting out from a low initial base, firms' expectations of a large clean-energy market in the future would be a sufficient incentive to invest in it.

As enough players shift investment, the costs of clean technologies would be expected to fall as would the cost of finance in what were formerly considered niche markets. The development of new business lobbies, supportive institutions and behaviours and new skills would be expected to reduce unit costs further. Of course, if clean technologies are reasonably well developed, this change in expectations is more likely to occur. Therefore, the government has a role both in shifting the expectations by credibly committing to climate policy, or by changing the initial conditions by investing in green infrastructure or funding clean energy research and thereby help shift the economy to the low-emission pathway[27]. The knowledge that innovation is path dependent should be an incentive for early action. If the rate and form of growth (green or dirty) is endogenous, then the ultimate cost of decarbonisation will be a function of investment and policy decisions taken early on which can set the economy on to an appropriate path.

A mayor, politician or businessperson will not want to invest in renewable energy and energy efficiency if 'experts' including economists presuppose it will be prohibitively expensive, hard to finance and lacking in market opportunities. Not investing means forgoing the benefits of learning-

[27] Acemoglu, D., Aghion, P., Bursztyn, L. and Hemous, D. 2012. The environment and directed technical change. American Economic Review, 102(1), 131–66.

by-doing. Underplaying the benefits means framing global climate negations solely in terms of common sacrifice for the greater good. This fosters a 'tragedy of the commons' race to the bottom, with distrust and ill-will delaying low-carbon investment and encouraging free-riding on the actions of others. Such paralysis characterises recent decades.

But things are changing. Social psychologists have long understood that solving coordination problems requires building expectations into models and generating 'common knowledge.'[28] The big innovation of the Paris Agreement is that it dropped the language of 'burden-sharing' and focussed instead on nationally determined voluntary contributions. This reflects the reality that self-interest, not shared sacrifice for the greater good, breeds cooperation. This in turn builds on a growing appreciation of the opportunities associated with a low-carbon transition. These include not only commercial opportunities associated with deploying (and fabricating and exporting) cheap and increasingly competitive new clean technologies, but also benefits from reductions in waste and inefficiency, improved energy security and reduced particulate pollution and congestion from clean compact cities. Particulate pollution alone causes welfare losses equal to 6% of global economic output annually, double that in Northern India and Eastern China. This is an example of new strategic complementarities emerging worldwide.

The UK is a small player and has to take the pace of the global transition as mostly given and exogenous (although we can and do influence e technology costs through innovation and deployment). However, the fact that the dynamics outlined above are playing out at the global level as big players such as china invest in decarbonisation means that the UK must at least be aware of the possibility of a fast transition policy needs to plan for this strategically as a risk management and hedging approach, just as the TFCD requests that companies take a forward look by outlining their business strategies to shareholders to show that their business model is resilient to, and has a place in, a world of a fast transition.

Don't let static forecasts undermine conditional optimism

None of the features above, including expectations augmentation, path dependency, strategic complementarities and games, are new to economics. Moreover, not all economists presuppose a costly transition by assumption. Some have focussed instead on the dynamics of growth embodied in these important network effects and feedbacks. Endogenous growth theory augmented the classical economic model by asserting that growth in total factor productivity does not just happen. It results from investments made in human, physical and other forms of capital with growing knowledge having the potential to complement and positively impact the productivity of other forms of capital.[29] The key intuition is that increasing returns to ideas overcome the diminishing returns to factors like labour and capital. Investing in mobile or wired computers induces smart ideas on how to use them, enhancing the returns to developing new software and algorithms. This further increases the value of, and demand for computers. Investment in physical and knowledge capital begets increased output and generates resources for further investment.

Endogenous growth theory provides the evidence base required to be optimistic about a low carbon transition. In this regard, Paul Romer (who with William Nordhaus won the Nobel Prize in Economics in 2018) distinguished between 'complacent optimism' and 'conditional optimism'. He writes: "Complacent optimism is the feeling of a child waiting for presents. Conditional optimism is the

[28] K. Thomas, O.S. Haque, S. Pinker, and P. DeScioli, "The Psychology of Coordination and Common Knowledge," *Journal of Personality and Social Psychology* 107 (2014): 657–76.
[29] See Romer, P., 1990. Endogenous technological change. Journal of Political Economy, 98(5), pp. S71–S102.; Solow (1994), 'Perspectives on growth theory', Journal of Economic Perspectives, 8(1), 45–54. Acemoglu, Daron (2009). "Endogenous Technological Change". Introduction to Modern Economic Growth. Princeton University Press. pp. 411–533.

feeling of a child who is thinking about building a treehouse. 'If I get some wood and nails and persuade some other kids to help do the work, we can end up with something really cool.'" He adds "What the theory of endogenous technological progress supports is conditional optimism, not complacent optimism… Instead of suggesting that we can relax because policy choices don't matter, it suggests to the contrary that policy choices are even more important than traditional theory suggests."

Romer was always clear that innovation which drives endogenous growth is not limited to technological capital and knowledge capital; it also applies to rules, governance, and policies, all of which drive total factor productivity. He argues that social rules often hold back the potential introduction and exploitation of new technology. Indeed, new technologies are potentially harmful if not accompanied by rules that make growth sustainable—for example, rules that limit pollution, soil degradation, and overfishing. It's important to recognise that this is more than just about learning by doing[30].

What Romer is saying is that the barriers to overcoming major challenges are not primarily economic or technological, they are political, cultural and institutional. This explains why economists consistently get the future wrong. We do not know the form of the technologies and behaviours that will ultimately deliver a zero net carbon world, nor do we know the precise costs. What we do know is that these costs will be a direct function of the decisions we take today. We also know that once it comes, change can come fast and be transformative. The bottom line is when faced with systemic technological transformation, policymakers, economists and investors would do well to spend less time predicting future and more time shaping it.

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[30] See: https://www.files.ethz.ch/isn/113646/1423916_file_TechnologyRulesProgress_FINAL.pdf.

ANNEX 4

Macroeconomic Impact of Deep Decarbonisation

Philip Summerton, Cambridge Econometrics

Background

This note summarises technical research[31] produced by Cambridge Econometrics and E3 Modelling for the European Commission (DG Energy) on the macroeconomic impact of deep decarbonisation using a CGE model (GEM-E3-FIT[32]) and a macro-econometric simulation model (E3ME[33]).

Modelling analysis for the European Commission assessed the macroeconomic impact for the EU-28 of meeting 2 degrees (2DEG) compared to the European Commission's Reference scenario (REF). The modelling does not include the impact of climate damages, only the impact of climate change mitigation actions in the form of reducing GHGs

The purpose of the note is to explain, in relatively simple terms, the underlying reasons for differences between the results from different economic models, and not a detailed description of the differences in the theory underpinning each model, to inform the CCC's decision as to whether to recommend tighter carbon budgets as the UK's contribution to limiting global warming within 1.5 degrees.

Summary of results

The first thing to note, is how similar the results are (tables below). For similar amounts of CO_2 reduction in Europe (and globally) both models suggest:

- a small impact on European GDP over the 30 year-period to 2050
- a small positive impact on European employment, leading to lower unemployment

The main point of difference is that GEM-E3-FIT suggests a small reduction in GDP (0.5%) between REF and 2DEG by 2050, while E3ME suggests a small increase in GDP (2.0%).

However, this difference is really very small: the REF implies an annual GDP growth rate of around 1.45% compared to between 1.43% (GEM-E3) and 1.52% (E3ME) for the 2DEG scenario.

E3ME	2020	2050	2020-2050
CO2 (mtCO2)			%
EU-28 CO2 (REF)	3109.5	2017.0	-35.1
EU-28 CO2 (2DEG)	3045.0	911.6	-70.1
GDP (2020 = 100)			%
EU-28 GDP (REF)	100.0	157.4	57.4%
EU-28 GDP (2DEG)	100.0	160.8	60.8%
Unemployment (%)			pp
EU-28 Unemployment (REF)	10.9	7.5	-3.4
EU-28 Unemployment (2DEG)	9.2	7.1	-3.7
GEM-E3-FIT	2020	2050	2020-2050

[31] https://ec.europa.eu/energy/sites/ener/files/documents/technical_analysis_decarbonisation_scenarios.pdf
[32] Developed originally as GEM-E3 and extended to incorporate a treatment of finance and technical progress (see http://e3modelling.gr/images/files/ModelManuals/GEME3_manual_2015.pdf)
[33] See www.e3me.com

CO_2 ($mtCO_2$)			%
EU-28 CO_2 (REF)	3281.3	2175.5	-33.7
EU-28 CO_2 (2DEG)	3281.3	811.7	-75.3
GDP (2020 = 100)			%
EU-28 GDP (REF)	100.0	154.8	54.8%
EU-28 GDP (2DEG)	100.0	154.0	54.0%
Unemployment (%)			pp
EU-28 Unemployment (REF)	9.2	6.6	-2.6
EU-28 Unemployment (2DEG)	9.1	6.5	-2.6

What explains the reason for the difference in the GDP result?

A more ambitious decarbonisation path entails a higher rate of investment in both models (cumulative economy-wide investment in EU-28 is 2% higher by 2050), reflecting:

- the substitution of capital for energy (greater energy efficiency)
- the substitution of capital-intensive renewable technologies for fossil-fuel intensive technologies in power generation
- the substitution of electric appliances for fossil-fuel-based appliances in final energy use
- potentially, the early scrapping of fossil-fuel based equipment

The impact that greater investment has on the economy depends on the degree to which an economy is constrained. If the economy is constrained, greater investment will lead to higher prices

Two types of constraints are considered:

- financial (capital) constraints: can the additional investment be financed without crowding out other investments?
- physical constraints
  - labour supply: is there enough slack in the labour supply to meet the additional demand in the economy?
  - skills: can labour switch between sectors and occupations?

The difference in the results between the two models comes from the treatment of finance, since both models show the labour market not to be a constraining factor in transitioning to a low carbon economy. In E3ME, there are no constraints on finance; whereas the GEM-E3-FIT model, while relaxing the assumption that investment must come from in-year savings has slightly higher interest rates as a result of slightly higher borrowing in the 2DEG scenario.

Neither model explicitly considers skills constraints between sectors which merits further investigation and is discussed in the technical paper referenced.

What's the evidence on financial constraints?

With regard to financial constraints, at a macro level the larger call on finance for investment in 2DEG comes in the context of a decline in the ratio of private sector debt to GDP over time in REF. The speed of that decline is less under 2DEG, but at this broad macro level the burden of indebtedness is not rising over time.

However, the increase in investment and debt is not spread evenly across the economy but is focused on the sectors in which decarbonisation is strongest, notably in power generation. In E3ME's results the scale of investment in electricity is higher in 2DEG and especially in the last decade, with the result that the estimated debt carried by the electricity industry rises sharply as a ratio to its gross operating surplus, suggesting that financial investors may require a higher risk premium in lending rates. E3ME assumes that the power generation capacity required to meet electricity demand will still be built, but the higher cost of borrowing by the sector is assumed to be passed on to electricity consumers. In a sensitivity test, in which a higher interest rate was required from the electricity sector, there is a much larger impact on the levelised cost of electricity of the more capital-intensive technologies compared with combined-cycle gas turbine technology, and these costs are (by assumption) passed on to electricity users, raising the electricity price to those users by about 10% by 2050.

What's the evidence on physical and skill constraints?

With regard to *physical* constraints, again at a macro level the difference between REF and 2DEG is not large, in terms for example of GDP and labour demand, and so the impact of a tighter labour market on wage inflation is small. This reflects the fact that the main economic impacts of 2DEG compared with REF are structural, shifting demand and activity between sectors (from fossil-fuel dependent sectors to suppliers of investment goods).

Although a more ambitious rate of decarbonisation has important impacts at sectoral level, gains and losses by sector largely offset each other so that at macroeconomic level the effect is small. However, this is not the end of the physical constraints story, because resources released by a declining sector are not perfect substitutes for those required by an expanding sector. The potential for mismatch is mitigated by the long period allowed for the transition, but not necessarily eliminated.

The 2DEG scenario increases sharply the job losses in fossil-fuel related industries, adding to the large losses already envisaged in the REF scenario. Since these industries tend to be geographically concentrated (for reasons of geology or the dominance of large plants exploiting economies of scale), the trends highlight the issue of impact on particular communities and the challenge to replace the lost jobs and retrain workers. The job losses in these sectors in REF and 2DEG are larger than the reduction in the workforce that can be expected due to retirement of workers as they age over the decades.

As for potential *skill* constraints, the difference between 2DEG and REF is modest compared with the underlying trend over time expected in both scenarios. There is a substantial skills challenge in prospect with substantial restructuring of jobs in favour of high-skill occupations; stronger decarbonisation is expected to add to that challenge. The scale of the additional demand associated with stronger decarbonisation is not large relative to the number of jobs already envisaged across the whole economy, but it comes on top of a prospective mismatch of labour supply and demand. The impact is likely to be felt more strongly in very specific occupations in which 'greening' (new competences required to adapt to the growing demand for new technologies) is expected to occur.

Reflections and implications for the CCC

Given the broad overall consistency in the economic modelling results (between models in the referenced study and across other studies) and especially considering the difficulty in modelling inherent uncertainties in the period to 2050; further modelling of the GDP impact of setting tighter UK carbon budgets for the UK (to meet a 1.5-degree world) would seem to be unnecessary at this stage.

ANNEX 5

The Need for Sustainable Finance

Rain Newton-Smith, Confederation of British Industry

Overview

Tackling climate change requires action now to prevent risks that will crystallise in the future. Banks, insurers and investment funds have a real role to play in managing the financial risks of climate change and helping to provide capital to invest in renewables and other more sustainable technologies. Sustainable Finance has been highlighted and promoted by the European Commission as a key workstream for the current mandate and the political momentum it has gained over the past months shows no sign of stopping. The UK government and other national governments across the globe have also embraced the idea of sustainable finance and businesses must not be left behind in this trend.

Climate change has now become an important issue for banks and insurers and will soon become a central matter for all industry players when assessing the financial risks for their businesses. The management of the financial risks arising from climate change must therefore be explored fully to give firms the support and guidance they need to transition towards a more sustainable way of doing business.

Thus far, the problem for investors has been finding ways of properly assessing the environmental, social and governance impact of investments in green technologies and judging the expected returns from investments that are necessarily long-term in an uncertain policy framework. With the correct political framework, sustainable finance can address these issues by providing access to capital that will help secure funding for innovative technologies that will help a range of industries decarbonise. For energy-intensive industries, sustainable finance could help provide further capital for R&D on new innovative technologies that will allow this sector to further improve its energy efficiency and adopt carbon capture technologies that will be essential for a transition to net-zero emissions.

Green Finance Taskforce

The Green Finance Taskforce – co-hosted by BEIS and HMT – brings together senior leaders from the financial sector to work with industry to accelerate the growth of green finance. The Taskforce has two main aims at its core. The first is to further London as the leading world centre for green finance and to ensure the UK's existing capabilities continue to evolve to grasp this commercial opportunity. The second is to help ensure that UK plc has access to the right forms of capital to deliver against the Clean Growth Strategy and for the UK to benefit from the profound opportunity to green its economy.

In March 2018, the Green Finance Taskforce published a report 'Accelerating Green Finance'. In summary:

- The report highlighted the need for international alignment of interests, incentives and policies.
- The Taskforce sees the transition to a low-carbon economy as a major opportunity in the UK and that this cannot be achieved by Government alone.

- Climate-related risk is understood to exist by all financial actors but it is not yet priced into long-term financial thinking. Short time horizons in investment decision-making, information asymmetries, misaligned incentives, financial mis-education and perhaps most crucially, a lack of available data, co-conspire to under-allocate capital.
- There is great potential for decarbonisation and green investment in energy efficiency.
- The report recommends the Government to set up a new implementation committee, tasked to track progress on the recommendations made by the Taskforce.
- The UK's world leading financial services status means that the UK has direct access to the investment the UK needs. Meeting our carbon budgets will require high levels of investment i.e. investment in environmental technology, infrastructure and services.

Recommendations from the Green Finance Taskforce:

1. **Relaunch UK green finance activities through a new unified brand**
    - The Government and the City of London should establish a new Green Finance Institute brand under which strengthened Green Finance Initiative capacity is established.
    - This new Institute should set up a Green Fintech Hub.
    - The Government and the new Institute should deliver a joint diplomatic strategy on green finance.

2. **Improve climate risk management with advanced data and analytics**
    - Private sector, academia and the Government should establish a Centre for Climate Analytics.

3. **Implement the recommendations of the Task Force on Climate-related Financial Disclosures (TCFD)**
    - Relevant financial regulators should integrate the TCFD recommendations throughout the existing UK corporate governance and reporting framework.
    - The Government and relevant financial regulators must clarify in their guidelines that disclosing material environmental risks, including physical and transition climate-related risks, is already mandatory under existing law and practice.

4. **Drive demand and supply for green lending products**
    - The Government should extend 2035 EPC targets from residential properties to commercial properties by the end of 2018 and introduce a requirement for operational energy ratings from 2020.
    - The Government should introduce Green Building Passports for residential and commercial properties by 2020.
    - The Government should complete research to understand the opportunities and costs of using a range of fiscal measures to boost demand for energy efficient retrofits in 2019, and pilot fiscal measures alongside mortgage products from 2019.
    - The Government should provide short-term incentives to pump prime the green consumer loans and green mortgage markets.
    - UK lenders should work towards promoting awareness and mainstreaming a consideration of 'green' factors into all their mortgage lending decisions.

5. **Boost investment into innovative clean technologies**

- The Government should set up a Green Investment Accelerator for early stage technology grant funding.
- The Government should establish a dedicated public-private green venture capital fund.
- Increase commercial opportunities for UK businesses through public procurement opportunities.

6. **Clarify investor roles and responsibilities**
    - The Government should require that the Statement of Investment Principles include statements on the extent to which social, ethical and environmental issues (including climate change) are considered.
    - The Government should clarify that investment consultants should have sufficient expertise and competency on ESG issues.

7. **Issue a Sovereign Green Bond**
    - The Government to issue a Sovereign Green Bond.

8. **Build a green and resilient infrastructure pipeline**
    - The Government should publish a National Capital Raising Plan explicitly designed to align UK infrastructure planning with the delivery of the Clean Growth Strategy and the 25 Year Environment Plan.

9. **Foster inclusive prosperity by supporting local actors**
    - The Government should set up a Local Development Finance fund.
    - The Government should set up Clean Growth Regeneration Zones.

10. **Integrate resilience into the green finance agenda**
    - The Government should establish a national resilience unit to coordinate and champion climate resilience and ensure Government investment is 'future proofed' to climate change.
    - The Government should publish an action plan to develop the resilience market.

There is a range of other initiatives related to sustainable finance. For example, the Green Finance Initiative, in partnership with the UK Government, brings together international expertise from across the financial and professional services sector. It aims to:

- Provide public and market leadership on green finance
- Advocate for specific regulatory and policy proposals that might enhance the green finance sector worldwide
- Promote London and the UK as a leading global centre for the provision of green financial and professional services

Another initiative is the Financial Stability Board's Task Force on Climate-related Financial Disclosures, the report of which was referenced in the main report above. More broadly, in December 2017 the Bank of England co-founded the Network of Central Banks and Supervisors for Greening the Financial System in December 2017, and, as announced in the Industrial Strategy, the UK Government is working with the British Standards Institution and the Green Finance Initiative to develop the world's first green financial management standards.

London may have an important role to play as a centre for sustainable finance. The first offshore green bond issued by an Indian entity and the first green bond issued by a Chinese bank were both listed on the London Stock Exchange and 50 green bonds denominated in seven currencies with a value of $14.8 billion are now listed in the UK. In July 2017, Anglian Water released the first ever public utility Sterling Green Bond on the London Stock Exchange.

Mortgage providers also have an important role to play, including by improving mortgage affordability assessments on energy bills, and developing a range of innovative new “green mortgage” products to encourage consumers to purchase more efficient homes, or improve the efficiency of existing homes.

ANNEX 6

A Just Transition?

Karen Turner, Centre for Energy Policy, University of Strathclyde

Origins of the Just Transition concept

The initial foundations of the Just Transition concept seem to have been laid in a document titled 'Guidelines for a just transition towards environmentally sustainable economies and societies for all' published by the International Labour Organisation (ILO) in 2015. While acknowledging the basic principle of sustainable development in terms of how the needs of the present generation should be met without compromising the ability of future generations to meet their own needs, the ILO document clearly aims to shift attention to current generations. It focuses on the nature of the low carbon *transition* and the need to ensure acceptability with "agents of change" (p.4) in both current and subsequent timeframes. The ILO document states (p.4), that "[T]he four pillars of the Decent Work Agenda – social dialogue, social protection, rights at work and employment – are indispensable building blocks of sustainable development", and goes on to discuss issues around decent work for all, reducing inequalities and effectively eliminating poverty in *all* generations.

The 2015 UNFCC Paris Agreement, just a few months later, very specifically focuses on the issue of work/employment by stating that the agreement is subject to: "Taking into account the imperatives of a just transition of the workforce and the creation of decent work and quality jobs in accordance with nationally defined development priorities" (UNFCCC, 2015, p.2). That this element of the agreement refers to 'nationally defined development priorities' may arguably be set in a broader context of this international agreement being set in terms of not overly interfering with or intending to impede national priorities with respect to economic development more generally.

Understanding and interpretation of the Just Transition concept going forward

The ILO is directly referenced, and its broader focus around 'fairness' and 'equity', is apparent in the Scottish Government's stated motivation for establishing the Scottish Just Transition Commission (JTC), the launch of which was formally announced by Roseanna Cunningham, Scottish Environment, Climate Change and Land Reform Secretary, at the November 2018 UNFCCC Conference. In the web-page introducing the Scottish JTC, the UNFCCC Paris Agreement statement above is cited, but the purpose of the JTC is stated as advising Scottish Ministers on how to apply the Just Transition Principles as set out in the ILO 2015 document. The headline role of the JTC is stated as "advising on a carbon-neutral economy that is fair for all", and the Scottish-specific policy context is set in terms of growing a low-carbon, inclusive economy that meets the ambitions of both Scotland's Economic Strategy and the Climate Change Bill (which commits Scotland to being carbon-neutral by 2050).

As argued by the European Zero Emission Platform in a 2018 report (on 'The Role of CCUS in a Below Two Degrees Scenario) a crucial issue may be the need for a just transition to be "one that is *perceived* as not unduly costly to people locally and globally" (ZEP, 2018, p.5; author's emphasis). The ZEP reports focus in this regard is an economic one, stating: "A just transition can sustain the economic contribution of the sectors in which we have already invested. It can create new jobs and preserve existing ones, and thereby generate economic growth" (ZEP, 2018, p.5). In this regard, the ZEP report cites several examples of this author's own work[34] considering how technologies

[34] Turner, K. et al., 2018. 'Making the macroeconomic case for near term action on CCUS in the UK? The current state of economy-wide modelling evidence', University of Strathclyde, https://strathprints.strath.ac.uk/63554/1/Turner_etal_IPPI_2018_Making_the_macroeconomic_case_for_near_term_action_on_CCUS_in_the_UK.pdf

employed in delivering low or zero carbon outcomes may generate net gains in employment and GDP. This work argues that a key route to such outcomes is through sustaining and/or growing strong domestic supply chain linkages, which in turn is a core focus of the UK Industrial Strategy.

On the other hand, that a wider consideration of issues and outcomes is likely to impact political and public perceptions of a 'just transition' is equally well evidenced. For example, recent 'gilets jaunes' protests in France seem to have been sparked by concerns about the fairness of fuel duty rises. This example serves to highlight just how important it is to understand what public concerns may be over ensuring that the low carbon transition a fair and equitable one. Thus, it is crucial that Governments address – *and be seen to address* – issues of fairness and equity in the low-carbon transition. However, it would be wrong to conclude that climate policies are inherently unpopular – there are plenty of examples of highly successful climate measures. But what the protests do highlight is the importance of attending to the political economy of climate action in ensuring a 'just transition', however it may be specifically defined.

ANNEX 7

A Societal Lens on Accelerating the Pace of Energy Transition[35]

Mallika Ishwaran, Shell International

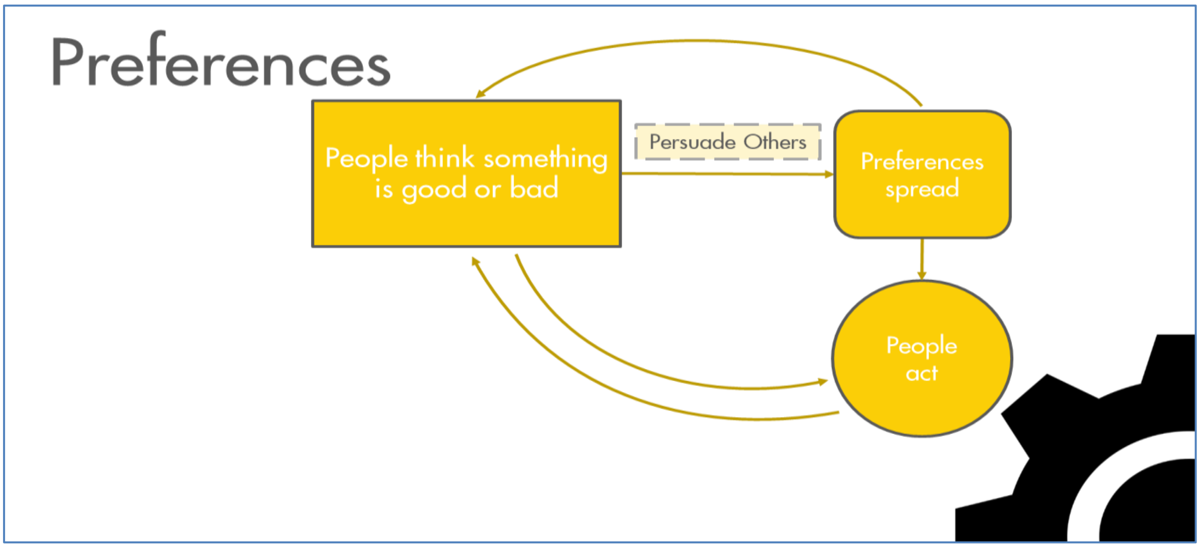
Meeting the ambition of the Paris Agreement requires an unprecedented scale and speed of change in how energy is produced and consumed – or an intensification of the energy transition. This requires understanding the motivations of the different actors in the energy transition and aligning around common interests – to create areas of common good that intensify the pace of change.

I. Intensifiers of the energy transition

The low carbon energy transition is underway, with changes in how energy is produced and consumed and enabled by new low carbon technologies, infrastructure, and policy frameworks and institutions. Positive feedback loops can intensify the transition, by accelerating it and/or increasing its scale. These can be considered in the context of the four key sets of actors in the energy transition – society (or citizens), government, business, and consumers.

1. Positive feedback loops in preferences, which cause society to act

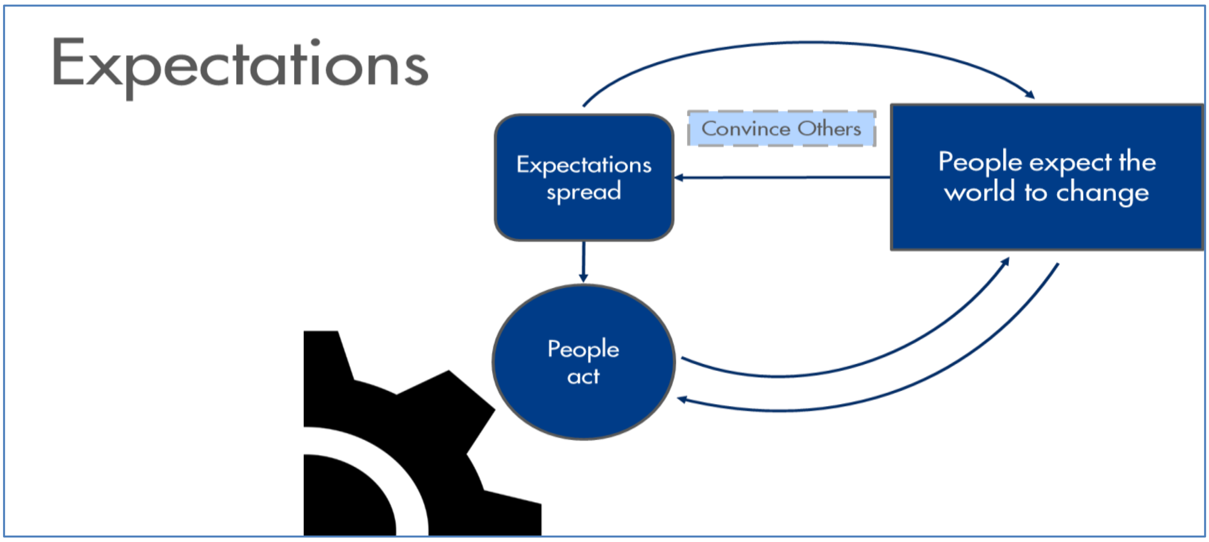
A transition can be intensified if preferences are influenced by a virtuous cycle of belief that the transition is good. When people think something is good (or bad) this can persuade others, which can cause preferences – the belief that something is good (or bad) – to spread. As preferences spread, this creates a positive feedback loop – i.e., persuasion spreads preferences further and the spread of preferences makes the persuasion easier. When people have a preference, they act accordingly. Such action can persuade others and spread the preferences further, creating a second positive feedback loop. The spread of preferences about what society should or should not be doing have been powerful in past energy transitions. For example, Japan and France's embrace of nuclear power as a signifier of a technologically advanced society or Germany's anti-nuclear movement which saw nuclear as an environmental threat.



[35] Taken from 'China's energy revolution in the context of the global energy transition', Shell International and the Development Research Center of the State Council of China, *Eds.,* Springer Publishing (forthcoming 2019).

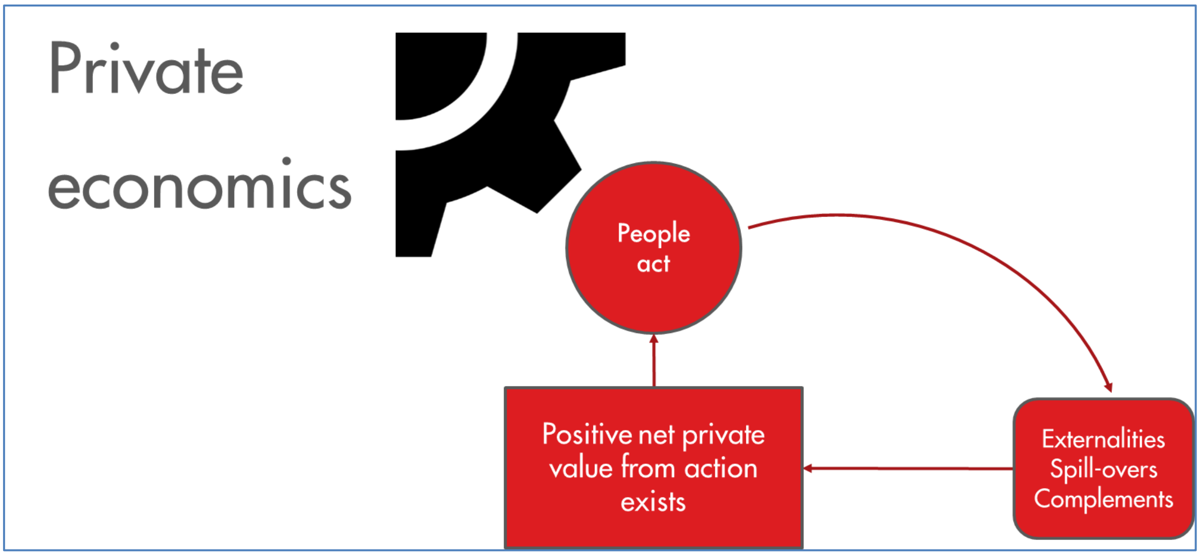
2. Positive feedback in expectations, which cause consumers to act

Expectations are also an intensifier. As more people expect the transition to happen, they will act as if it is happening. As with preferences, when people expect the world to change, this can convince others so that they too expect it to change. Moreover, when people expect a change, they act accordingly, which can further convince others to expect change. This creates a positive feedback loop – i.e., consumer actions in line with their expectations further convinces others to act. The difference between expectations and preferences is that expectation describes what is likely to happen whereas a preference is a view about what ought to happen. For example, a person can expect something to happen even if they would prefer it not to occur. The expectations of consumers have been an important intensifier in past energy transitions, as they make choices and purchases that they expect to serve them best in the future. For example, in the current transition, the purchase of electric vehicles could be in the expectation of future climate policies and regulation.



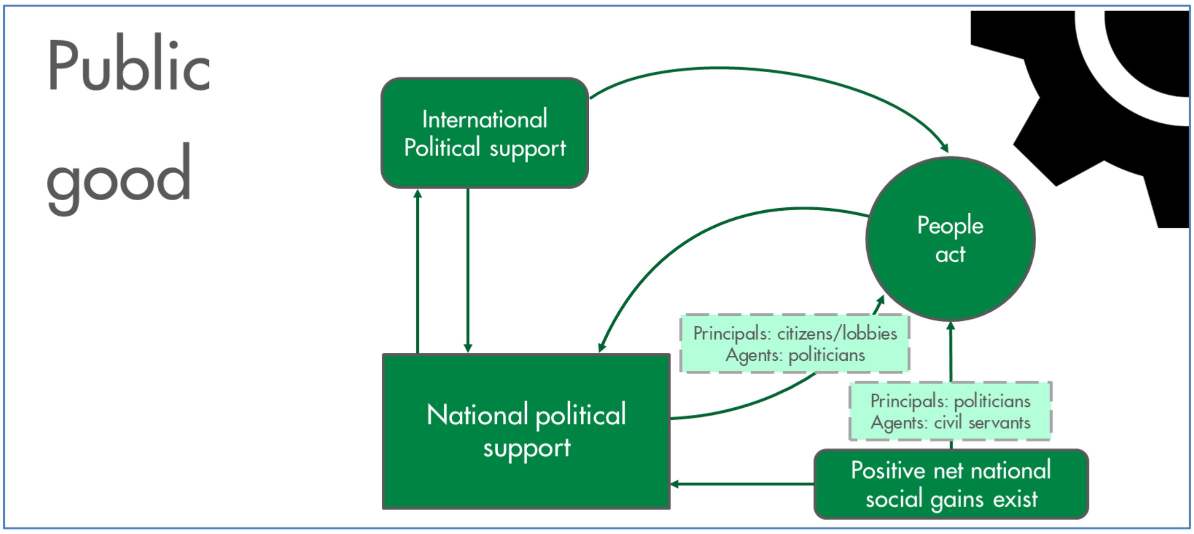
3. Private economics, which cause businesses to act

Private economics drive action – which can further improve the private economics of that action through positive spill-overs – and encourage even further action. People and businesses will act if it generates value for them. This is described as positive net private value, which simply means that the benefits from the action are greater than the cost of undertaking that action. When action is taken based on private economics, this can change the net private value of future action via externalities, positive spill-overs, or providing a complementary good. For example, the cost of wind power has declined as deployment has increased due to the positive spill-over of learning effects. This creates a positive feedback loop – i.e., as action increases the net private value of future action, this encourages future action, which can further increase the net private value of future action.



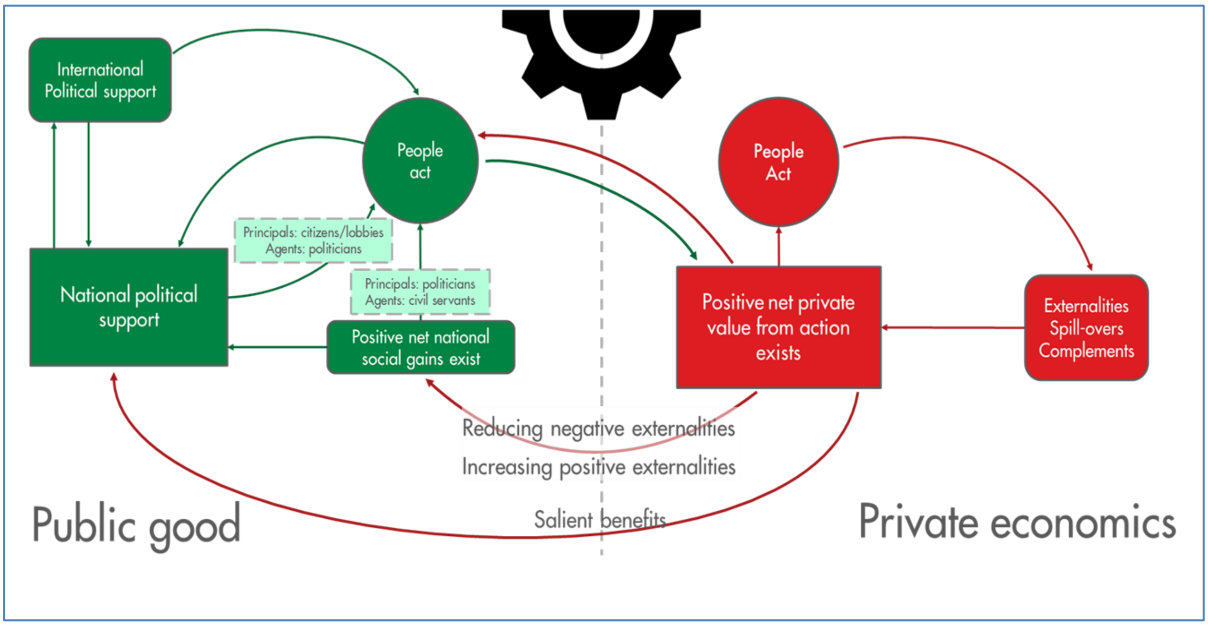
4. Public good, which causes government to act

Governments tends to act as the public economics or the politics of the transition improve, specifically, if the action generates value for society or if there is political support for it. When there is an action that provides positive net national social gains, it can generate national political support, or it can directly drive policy action. If political support exists, politicians act (as agents) on behalf of citizens or lobby groups (the principals). If the action generates value but lacks a strong political response (either in support or in opposition), the policy-makers (as agents) may be able to act directly in interest of wider society (the principals). International political support can also modify national political support. For example, the Paris Agreement or the International Energy Agency have affected national political support for climate action and energy security, respectively.

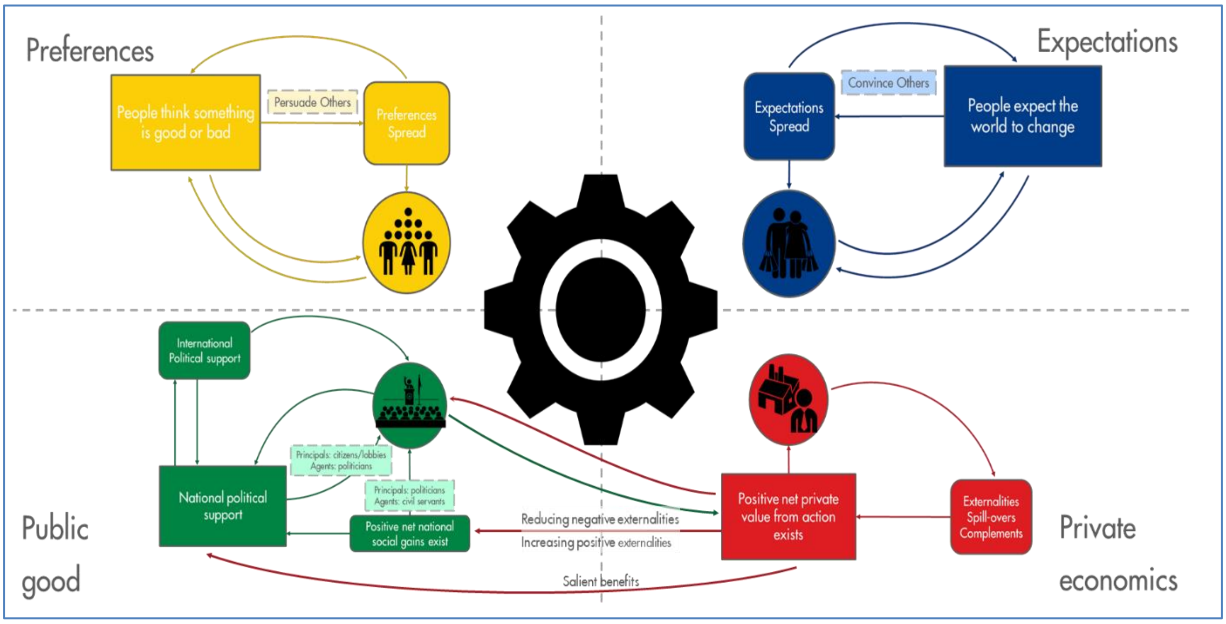


II. Leveraging areas of common interest

The private and public economics of the transition have strong positive feedback loops between them. At a minimum, social value is equal to the sum of private value. However, if there are positive externalities to private action, such as reduced carbon emissions, or negative externalities, such as pollution, then the social value of taking action will diverge from private value. Government action can increase net private value. For example, if subsidies are offered for renewable energy investment. Private value can also lead to government action, such as if public sector and state-owned enterprises act to generate private value. Private value can also affect political support if there are salient benefits (i.e., benefits that affect certain important groups within the economy or society), such as political support for protecting jobs in a certain industry. Thus, if the private value intensifies it also tends to intensify public value, and vice-versa, creating further feedback loops – and a virtuous and reinforcing cycle – between public and private action.



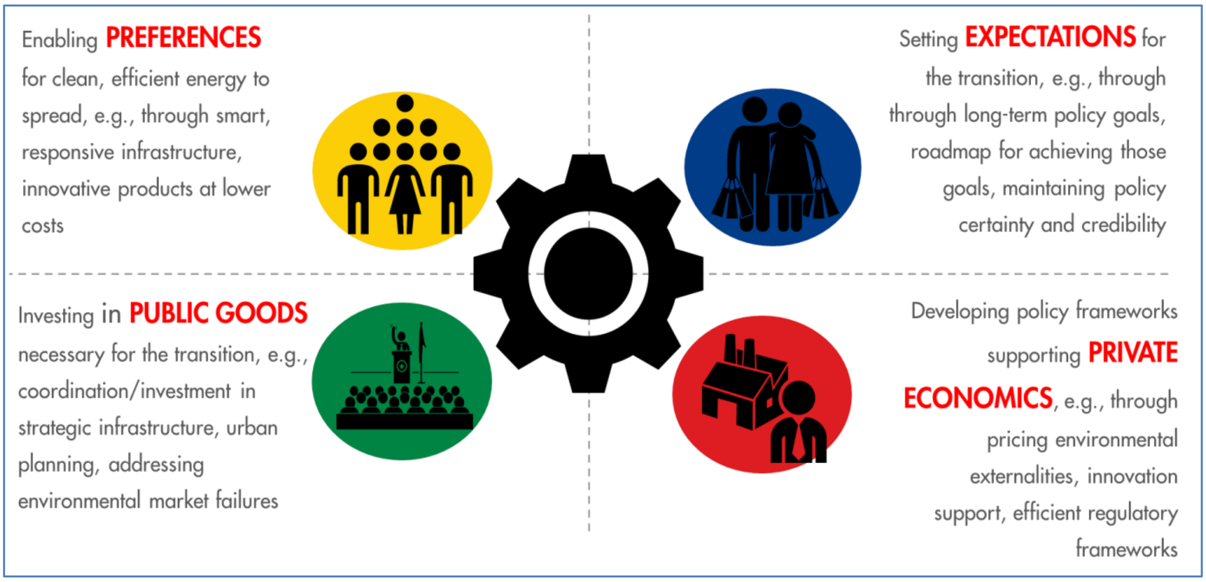
However, all four intensifiers of the transition come together to accelerate and scale change. As discussed in the previous section, societal preferences, consumer expectations, the private economics of firms, and the public good (which is the responsibility of government) all contain positive feedback loops that can intensify the motivation to act. Moreover, these four intensifiers work together. For example, if social preferences are creating consumer expectations that are causing people to act in a certain way – for example, demanding low carbon energy and related goods and services – this could increase the attractiveness of certain investments and cause businesses to act to meet that demand. This could, in turn, create the political conditions and support for further government action to drive the energy transition.



III. Role of policy in creating areas of common good

Policy accelerates the transition by giving momentum to intensifier(s). Given the policy-led nature of the current transition, government action to correct for environmental market failures is essential to drive behaviour change among consumers (and society more widely) and action by businesses to invest in new low carbon technologies. For example, by making the case for political support, offering subsidies to improve the private economics of action, or running information campaigns to inform preferences and/or expectations. Specifically:

- **Society:** policy can enable preferences for clean, efficient energy to spread, for example by demonstrating the potential for smart, responsive infrastructure, and innovative products at lower costs.
- **Consumers:** policy can set expectations for the transition, for example through setting long-term policy goals, and providing a roadmap for achieving those goals, then maintaining policy certainty and credibility as the roadmap is delivered.
- **Firms:** policy can develop frameworks that support private economics, for example by pricing environmental externalities, supporting innovation, and implementing efficient regulatory frameworks.
- **Government:** policy can invest in public goods necessary for the transition, for example by coordinating or directly investing in strategic infrastructure, urban planning and addressing environmental market failures.



Policy also has a key role in smoothing the transition, by synchronising feedback loops**.** It is possible that if one intensifier changes more slowly than others, it may hold back the transition, which will reduce the benefit of positive feedback loops that occur in the other intensifiers. Thus, in addition to giving an intensifier momentum, policy-makers also have an important role in keeping the rates of change in social preferences, consumer expectations, private economics, and the public good synchronised as a transition happens.

ANNEX 8

What Makes Good Policy?

Rain Newton-Smith, Confederation of British Industry

What makes good policy?

There are fundamental principles which lay the foundations for good policy making, primarily underpinned by long-term clarity on the regulatory landscape. This is vital for attracting private investment as businesses value the benefit of regulatory certainty. The role of markets should be prioritised, as open competition has been demonstrated as an effective way of determining the most cost-effective solutions and technologies. When policy is introduced or reformed, this process should always be transparent, predictable, and based on cost-benefit analysis. These principles are particularly important for policies relating to decarbonisation which typically require long-term action, significant investment from the private sector, and business and government supporting change in consumer behaviours.

The remainder of this paper considers these principles in more depth, with examples from the power, energy and transport sectors that demonstrate good and bad policy impacts. We also look to the opportunities for good policy development in other sectors that require significant decarbonisation in the coming decades.

Power sector

Long-term policy frameworks

The power sector operates in a landscape of complex policy and regulation which were introduced or developed in response to wider economic, political and environmental changes. Much like other sectors political changes in particular have wide-reaching impacts on the extent to which this sector can adapt and develop, retain investment and protect competition, rather than take a step back.

Good policy needs to provide long-term certainty and predictability for investors and not be subject to excessive impact by political change. Regulation must also be designed to be adapted when necessary to take account of changing technology. An over-reliance on primary legislation can make regulation difficult to adapt when needed.

The energy sector maintains a range of policies which are indeed long-term, including Electricity Market Reform (EMR), nuclear power policy, the Climate Change Act and Carbon Budgets. But equally, some others are short-termist (RO, FiT, RHI) or have been removed without adequate replacements.

Some policies, either long- or short-term, impact sectors other than energy and as such, are for the most part, not aligned. Carbon Pricing for example impacts the energy sector in a different way to aviation. When policies are inconsistent in this manner, they can lead to unintended consequences. For example, regional agreements such as the EU Emissions Trading System (ETS) places a double burden on European air carriers in the overlapping compliance requirements from the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) 2021 regulation.

This is why we believe good policy needs a whole systems approach across businesses, sectors and regions, acknowledging the fact that policies which suit one sector, may not suit another. In this sense, a balance should be made between certainty and flexibility. In the long-term, this may have wider positive impacts on efficiencies and cost.

EMR

The introduction of Electricity Market Reform (EMR) was a prime example of policy reform, following a need for large-scale change in industry. There was a clear need to act on climate change and build new low-carbon electricity generation capacity, while maintaining secure energy supplies, and making these changes at the lowest possible cost.

The embodiment of this ‘trilemma’ within the EMR policy framework provided a stable policy direction for a sector operating under layers of complex regulation.

<u>Helpful:</u>

- Provided a robust call to action for the market to bring forward new low-carbon technology and infrastructure;
- Provided a business case for firms providing back up/ancillary services to ensure security of supply;
- Provided a legally binding, credible foundation which included a review every 5 years – good policy should be reviewed over the period of its lifetime to ensure it remains fit for purpose;
- Brought together energy and climate change to be dealt with as one, holistic action (Capacity Market [CM], Contracts for Difference [CfD] with an Emissions Performance Standard, and Carbon Pricing)

<u>Unhelpful:</u>

- Not consistent across the two main investment mechanisms. For example, the CM and CfD do not provide a level playing field for all technologies to participate, and are not transparent in their governance structure (more below);
- Provided a blanket set of policies for a range of sectors which meant inconsistent and unfair impacts on some industries over others (Carbon Pricing, for example is a blanket policy which did not allow for flexibility or exemptions for sectors (EIIs) which must deal with indirect costs, leading to a severe lack of competitive advantage internationally)

Role of markets

Prosperous and competitive businesses thrive when the market dictates the state of play, with limited action from Government, against the backdrop of a strong regulatory framework to address externalities where needed. Of course, well-functioning markets are best when supported by long-term, transparent policies which can reduce costs and increase efficiencies in supply.

Capacity Market (CM)

The market-wide CM remains the right mechanism for promoting the necessary investment to maintain security of supply. In facilitating competition, it has helped deliver substantial cost benefits to the consumer, despite the recent ECJ ruling against the CM (good policy should adhere to state aid rules in their entirety).

Good policy should clearly define the roles and responsibilities of those in the governing role and should involve as little administrative work as possible.

<u>Helpful:</u>

- Allowed the market to set a price for capacity, without interference from the Government;
- Targets set within the policy, providing transparency, allowing businesses to plan ahead and better manage investment risk.

<u>Unhelpful:</u>

- Lack of transparency around governance of the policy, especially regarding the clear delineation of roles and responsibilities of those governing;

- Extremely intensive administrative processes involved in pre-qualification and when returning for the next auction;
- Heavily imbedded in legislation which makes reforms time consuming and difficult to achieve. This could easily be fixed by transferring much of the regulation into the policy's rules;
- Lack of clarity within the policy's rules themselves, leading to confusion over first point of contact for queries and lack of advice on policy interpretation;
- Lack of strong enough penalties for non-compliance.

Contracts for Difference (CfD)

Through market mechanisms and competitive auctions, the CfD framework has been a successful tool for delivering investment and bringing forward low-cost low-carbon generation.

It is important that the CfD regime (based on competitive auctions) is maintained since this joint industry and Government effort has meant that significant cost reductions have been achieved. For example, the target of reaching £100/MWh for offshore wind was achieved four years early and the last auction saw clearing prices well below expectations, with capacity secured at £57.50/MWh.

The CfD framework was also used to secure the investment in Hinkley Point C, at a price of £92.50/MWh. Follow-on nuclear projects have the potential to deliver at lower costs, as experienced by other technologies. While nuclear was not part of a competitive auction, a negotiation process meant the CfD could still be used to secure private sector investment.

Helpful:

- Provided a robust call to action for the market to bring forward new low-carbon technology and infrastructure;
- Clear dictation of the forward pipeline and advance notice of auctions with a set timeline and budget, allowing for market visibility, risk allocation, forward planning and investor confidence;
- Results driven policy via the implementation of milestones for delivery and incentives for compliance.

Unhelpful:

- Success of the policy is impacted by wider political challenges and heavily dependent on external policies, such as planning.

Sector-specific approaches

As noted above, blanket policies are not effective in achieving desired outcomes. They do not necessarily provide credibility or transparency and for the creation/development of climate change policy, these impacts must be considered. In the context of raising ambition and implementing a stronger goal, attention and guidance must be paid to individual sectors whilst still adhering to any possible overlaps where sectors merge – again a balance must be struck between sector-specific policy and a whole systems approach.

There is merit in the Government creating sector-specific roadmaps where sector-specific action is to be taken. Such roadmaps should detail the key measures and actions needed to reach the desired outcome, as well as include incentives the Government will put in place to achieve this. They have the capability to provide sector-specific milestones for progress which can help with predictability and certainty for investors and can highlight any joined policy encouraging collaborative working across sectors.

Technology choices

As noted above, market-led policies with as little Government interaction as possible provide the best environment for businesses to operate, attract investment and innovate. In such environments, new technologies can also develop which can bring help down the overall policy costs.

In the context of energy policy, good policy allows the market to decide the lowest-cost technology, based on market-wide competition and market-led principles.

For some technologies, support is needed to enable them to compete and be given the same access as mature technologies. However, in order to do so, all technologies should be given the same opportunity and the same access. This currently is not the case, for example onshore wind is no-longer allowed to compete in Contracts for Difference auctions, in the way that offshore wind does (onshore wind development is also effectively blocked by recent changes to planning laws). Such discrepancy is based on political choices, and could increase the cost of decarbonisation.

For innovative technologies, such as CCUS/BECCS - which have been deemed to be absolutely necessary as certain sectors decarbonise - we acknowledge that they may require direct government support to enable development and commercialisation at the early stages. This should lead to these technologies operating in the future at a commercial scale where they can compete against other low-carbon technologies.

Future policy recommendations

We have considered the role of good policy, drawing on experiences from the power sector that have led to positive and not-so-positive outcomes. Below, we consider the transport sector, and how these principles for good policy reflect on both the current policy landscape and future policy development.

Road transport

There is a growing focus on the impact of carbon emissions from transport now that it has become the UK's largest emitting sector. Road transport is the largest source of emissions from the sector, therefore a clear focus for government and business action. Unlike the power sector, decarbonisation of transport will rely much more on changing consumer behaviours as consumers will need to change the types of vehicles they buy and how they use them.

We consider below how long-term policy, markets, sectoral approaches and technology choices can be used in a positive way to drive the change that is needed.

Long-term policy frameworks

The transition to electric and other zero-emission vehicles will require a major shift in both manufacturing and consumer purchasing. The Government announced in 2017 that it wanted to "end the sale of conventional petrol and diesel vehicles by 2040". The Government's subsequent *The Road to Zero* strategy, published in 2018, set an interim target of 2030 for the sale of 50-70% of all new cars to be capable of CO_2 emissions of less than 50g/km and a zero-emission range of at least 70 miles. The principle of setting a long-term target is to be welcomed. However, there was a lack of consultation with car manufacturers, and the broader industry coalition needed to make this change possible which will affect the ability to meet this target.

Long-term targets should be used in conjunction with long-term policy frameworks. So far, the Government's targets have not been matched by policy of a similar timescale.

Incentives for change in consumer behaviour

The main source of consumer incentives for electric vehicles – the Plug-in Car Grant – has recently been reduced, and removed altogether for hybrid vehicles, with only several weeks' notice. The remaining grant allocation creates certainty for just a matter of months rather than years. This offers little confidence for consumers or car manufacturers. To effectively incentivise the transition to electric vehicles, since these remain more expensive than conventionally fuelled cars, a clear and long-term approach needs to be put in place. Government should develop a consistent incentive structure that includes a more predictable grant regime to make vehicles more affordable, tax exemptions, and shared approaches across cities and regions to make electric vehicle use more convenient (such as free parking while charging, favourable urban access and use of bus lanes where appropriate, and exemptions from tolls). This approach has supported the rapid uptake of zero-emission vehicles in Norway, which while not completely replicable in the UK, demonstrates how incentives can support rapid change in consumer behaviour. Other countries have seen the opposite effect when incentives are removed, such as Holland that saw a 96% fall in the sales of new plug-in electric cars following changes to tax measures for zero or low emission vehicles.[36]

Infrastructure development

Investment in electric vehicle infrastructure also lacks a clear strategy and long-term funding framework. For example, the *Road to Zero* strategy outlined funding for domestic charge points that would be guaranteed for less than a year, while there is no funding strategy for the mass roll-out of rapid vehicle charging infrastructure on the motorway network. The strategy focused attention on the work some (not all) local councils are doing to install charging options, and a £15m project by Highways England to ensure that users of the Strategic Road Network are always within 20 miles of a rapid charge point on 95% of the network. This is to be commended. However, a more defined strategy, including funding and targets, are needed to create a charging infrastructure network in keeping with the Government's 2040 ambitions. Good policy would involve better coordination between local councils and clearer targets from central government to help deliver adequate coverage of charging options. Further work with industry is required to assess what the minimum requirements are, and what further funding will be required to meet these goals.

Markets

Change on the scale required can only be delivered by a well-functioning market. Car manufacturers are investing in new technologies and vehicles are now coming to market. These vehicles are in significant demand from early-adopters, with long waiting lists reported for the latest models. It seems likely that this aspect of the market will function well, given the volume of investment being made and the global race by vehicle and technology manufacturers to sell electric vehicles, particularly given the decline in diesel sales.

Where intervention may be required to enable a well-functioning market is the charging network. A patchwork of charging networks is emerging, which may not support consumer access due to a variety of membership, payment and access options. Good policy from Government would support easy access, such as a "tap and charge" principle that would enable access to the whole market and drive competition between providers.

Sector-specific approach

Despite criticism of its content, the decarbonisation of road transport has been addressed through a sector-specific approach (the *Road to Zero* strategy). Developing, and enhancing, plans like this should give further clarity to business and consumers alike. For road transport, a further step will be to outline the long-term tax framework that will underpin this change. In particular, the future of Fuel Duty, which raises around £30 billion per annum in tax receipts, must be addressed. As more vehicles become electrified, less petrol and diesel fuel will be used in the future, therefore these receipts will decline and Government will need to consider alternative sources of revenue. Technology-enabled

[36] https://www.cbs.nl/en-gb/news/2018/21/number-of-all-electric-cars-increasing-rapidly#b95a2c0b-9ae2-4541-be26-174e829843c8

alternatives, such as pay per mile or virtual tolls may be an answer. But changes on this scale will require a significant conversation with industry and road users alike.

Technology choices

A technology-neutral approach to policy has seen industry in general move towards electric vehicles as their solution to delivering zero-emission miles. This has been market-driven, with a range of electrified technologies being developed (eg pure battery electric vehicles, and various forms of hybrid) that are contributing to a global expansion of zero-emission capable vehicles. The principle of technology-neutrality should be maintained as the market continues to develop.

However, better support for the commercialisation of specific technology is still needed. Hydrogen, for example, may support the decarbonisation of HGVs, maritime and rail transport, so it is right that Government supports industry with efforts to bring forward technologies that might assist sectoral decarbonisation challenges. Further benefits to targeted technology support might include new export opportunities if the UK is able to become a world leader in an emerging technology, such as hydrogen.

ANNEX 9

Membership of the Advisory Group

Paul Ekins (Chair), Professor of Resources and Environmental Policy and Director of the UCL Institute for Sustainable Resources, University College London

Mallika Ishwaran, Senior Economist and Policy Advisor, Shell International

Rain Newton-Smith, Chief Economist, Confederation of British Industry

Philip Summerton, Managing Director, Cambridge Econometrics

Karen Turner, Strathclyde University

Dimitri Zenghelis, Senior Visiting Fellow, Grantham Institute, London School of Economics