APPENDIX: UK COST ABATEMENT CURVE

Summary

The Task Force commissioned McKinsey to undertake what is currently the first comprehensive study of its kind for the United Kingdom. The study took as its starting point a previous McKinsey study on global greenhouse gas emissions. It then tailored that work to the UK, using a methodology developed over the past two years with the assistance of leading institutions and experts. A research team from McKinsey constructed a baseline forecast for UK emissions to 2030, drawing on a number of government and public sources. Working with Task Force members and other leading companies, the team then estimated the potential benefits and cost for over 120 different greenhouse gas abatement options that could help the UK meet its targets. These options were then represented in graphical form, illustrating the cumulative potential for emission reduction on the horizontal axis, and the cost per ton of emissions avoided on the vertical axis. This graph represents the first comprehensive UK marginal cost abatement curve.

We do not expect this study to be the final word on how to meet the targets, and fully expect that further analysis will be necessary to guide policy choices. However, the level of detail obtained by this study is higher than anything produced before in the UK, and offers some important insights on the task that faces us.

- While considerable improvements have been achieved, the UK targets will not be met without significant additional effort. All abatement options must be considered if we are to meet the targets.

- Meeting the 2020 target will be extremely challenging, requiring nothing less than a full implementation of all the options. By 2030 more technologies will have come on stream and old assets will have retired, making the 2050 target attainable.

- Meeting the targets implies a cost, which will need to be shared across business, government and consumers. The cost will be highest in the early years: we estimate that in 2020 it will be as much as 90 euros for every ton of greenhouse gases that is emitted. As 2030 approaches all the technologies needed to reduce emissions will become commercially viable, more options for reduction will be available and we expect this marginal cost to decrease to 40 euros per ton of emitted greenhouse gas. Furthermore, 60% of these initiatives will increase energy efficiency and 49% will constitute a net financial benefit.

- All sectors of the UK economy can contribute to the reductions, which will come in approximately equal measure from improvements in buildings, transport, power generation, and industrial processes.

- While we believe implementing all the abatement options will not require a reduction in consumption of goods and services, it will require a significant change in the way we consume

- Early action is critical. Many of the options that can deliver abatements over the next 20 years require the UK to start acting now. In particular, potentially difficult choices will have to be made on issues such as nuclear power, biofuels, carbon capture and storage, and on insulating the existing building stock.

1. Methodology

Marginal abatement cost curves are a standard tool used to illustrate the supply side economics of abatement initiatives aimed at reducing emissions of pollutants such as greenhouse gases. Starting from an estimate of baseline emissions, the costs and potential for additional abatement measures are calculated in order to construct a menu of options for abatement. McKinsey & Company developed the first global marginal abatement cost curve in 2005. The global cost curve was produced for different world regions including a cost curve for OECD countries. The latter provides the basis for this analysis as described below. The analysis presented in this document is a first estimate of the potential for emissions reduction in the UK, and an illustration of the methodology that could be used to guide policy making.

1.1 The baseline emissions projection and the cost curve

The starting point for constructing the marginal abatement cost curve is an estimate of the baseline scenario: a projection of how emissions might evolve if no additional initiative is taken beyond what is currently expected. A number of initiatives that could reduce emissions on top of the baseline are then analyzed. Each element of the cost curve is an estimate of the abatement potential of an initiative, as well as of its prospective annual cost[1]. The cost is plotted on the vertical axis, while the abatement potential is shown on the horizontal axis. Measures are arranged in order of cost, with the cheapest on the left, and the most expensive on the right.

1.2 Estimating the cost of abatement

The cost is calculated as additional to the baseline cost and is the annual *additional* operating cost (including depreciation of capital expenses) less potential cost savings (for example from reduced energy consumption) divided by the amount of emissions avoided. The abatement cost for wind power, for example, should be understood as the additional cost of producing electricity with this technology instead of the fossil fuel-based power production it would replace. This means that costs can be negative if the cost savings are considerable compared to the alternative. Transitional costs for implementing the initiative and opportunity costs associated with foregone alternative investments are not included.

1.3 Estimating the potential for abatement

The potential of an initiative to reduce emissions is estimated as a “technical” potential. The volumes should not be seen as forecasts, but rather as estimates of what is practically feasible in the timeframe chosen for the cost curve. For example, the technical potential for on-shore wind should be thought of as its potential, given the state of physical infrastructure, the availability of back-up generation, the availability for reducing emissions of suitable sites, etc. In principle many of these limiting factors can be changed, but the likelihood of it is considered small compared to the other choices available.

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[1] Costs are measured in euros per tonne of avoided emissions of CO_2e, while potential abatement is measured in million tonnes of CO_2e. CO_2 equivalent (CO_2e), is a measure reflecting the radiative potential of each gas in terms of the radiative potential of carbon dioxide.

1.4 Approach to constructing the UK cost abatement curve

The CBI Task Force aimed to provide high level estimates to understand the approximate potential for the UK, and to illustrate the need for a fact-based approach. It did not intend to produce a policy level cost curve that would allow decisions on each abatement initiative. For this reason the cost curve was produced with a mixture of 'bottom-up' and 'top-down' estimates: abatement initiatives that were large or of particular relevance to the UK were the subject of detailed analysis; abatement initiatives that were thought to be similar to the rest of OECD countries were estimated top-down, based on previous estimates.

For the UK, point estimate curves were constructed for 2020 and 2030, showing abatements for emission of all relevant greenhouse gases (GHG)[2]. For completeness international aviation and marine transport were also included in our calculation, even though they are not currently included in the government targets.

Emissions and related abatement initiatives are divided into five sectors that account for all emissions in the UK: power generation, industry, transport, buildings, and other (including forestry, agriculture, and waste.) Within these sectors, areas that were the subject of detailed analysis because particularly relevant to the UK include a large part of the power sector, industrial motor systems, residential buildings, bio-fuels and air transport.

It is important to stress that this analysis is not a forecast. It shows one potential route to meeting the targets, based on a specific set of assumptions reflecting our current knowledge.

1.5 Sources for estimates

The potential and cost were estimated based on a number of available public sources and were cross-checked through a series of expert interviews at multiple companies, industry experts, and through workshops. The year 2002 was chosen as the reference point for all the analysis, as this was the year for which all the required data was last available. This appendix is intended to give a high level view of some of the key assumptions and findings of the analytical work underpinning the report.

2. UK Cost abatement curves

The cost curves show that the target for 2020 is tough and that anything less than full implementation of all available measures will result in missing it. However, by 2030 the UK could be on track to meeting its 2050 target. While a full estimation of the total cost is beyond the scope of this analysis, our estimates indicate that the 2030 target could be met at a manageable cost.

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[2] Greenhouse gases considered: CO_2, CH_4, N_2O, HFC, PFC, SF_6

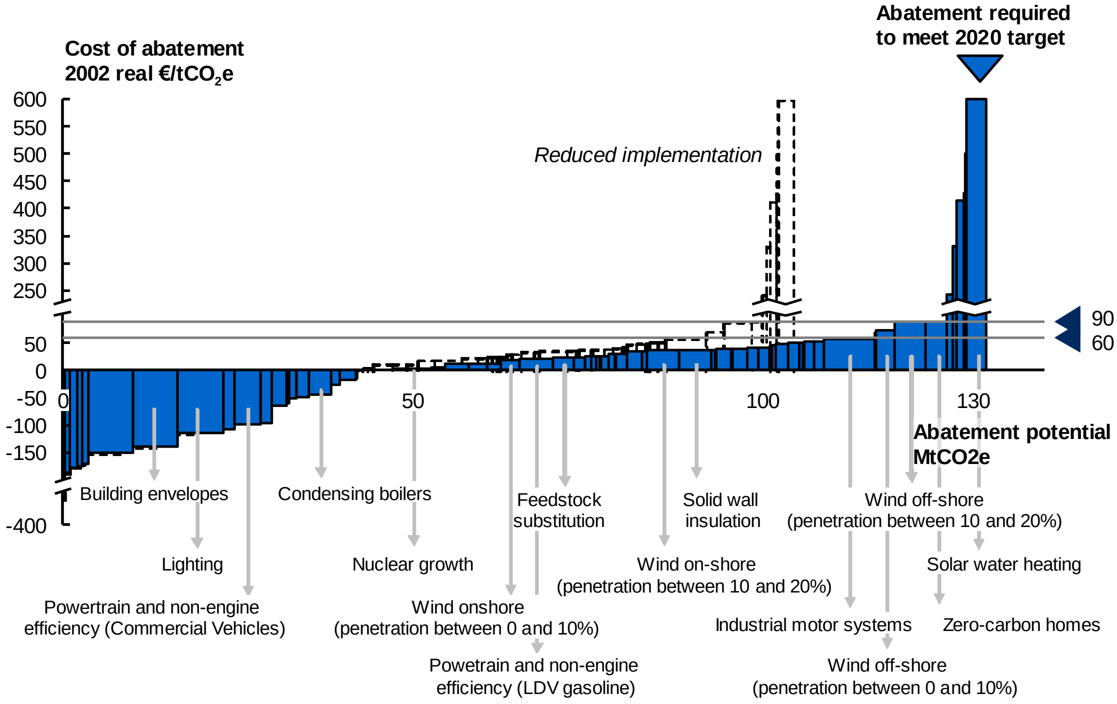

Figure 1 Cost curve for 2020. Vertical axis shows the cost of abatement in 2002 € per ton of CO2 abated. The horizontal axis represents the technical potential of all abatement options. The dashed line represents reduced implementation assumptions. Meeting the 2020 target is going to be very challenging and will only be possible if all additional abatement initiatives are adopted. 90-95% of the measures cost less than 60-90 €/tonCO2e (marginal cost is shown as the horizontal line)

1.1 Full and reduced implementation assumptions

The cost curve shows the maximum technical potential. However, the likelihood of capturing all of that potential depends on implementation, which maybe less than optimal. To illustrate what that would mean practically, we constructed an approximate scenario with reduced implementation, involving a general reduction of 20% for most measures. For some items a different reduction rate was chosen, based on specific assumptions. For example, potential for power generation was reduced by only 10%, as there are fewer players and decision making points, reducing complexity and transaction costs and increasing the likelihood of full implementation; biofuel penetration (ethanol) was reduced by 50%, given the high uncertainty related to cellulose ethanol costs relative to gasoline; penetration of zero carbon homes was also reduced by 50%, due to the wide variation in implementation costs and uncertainties surrounding micro-generation technology; penetration of smelt reduction technology in the steel sector was reduced by 50% due to the uncertainty of the technology; solid wall insulation was reduced by 25%.

2.2 The 2020 and 2030 cost curves

The full cost curve and the reduced implementation scenario can be used to verify the potential and marginal cost of meeting the targets. To meet the 2020 targets, abatements of over 130 MtCO2e are needed. Assuming a 100% implementation rate, 90-95% of the target could be reached at a marginal price of €60-90/t CO2e with contributions primarily coming from buildings and industry. With the reduced implementation scenario, additional abatements would need to be found to achieve the target.

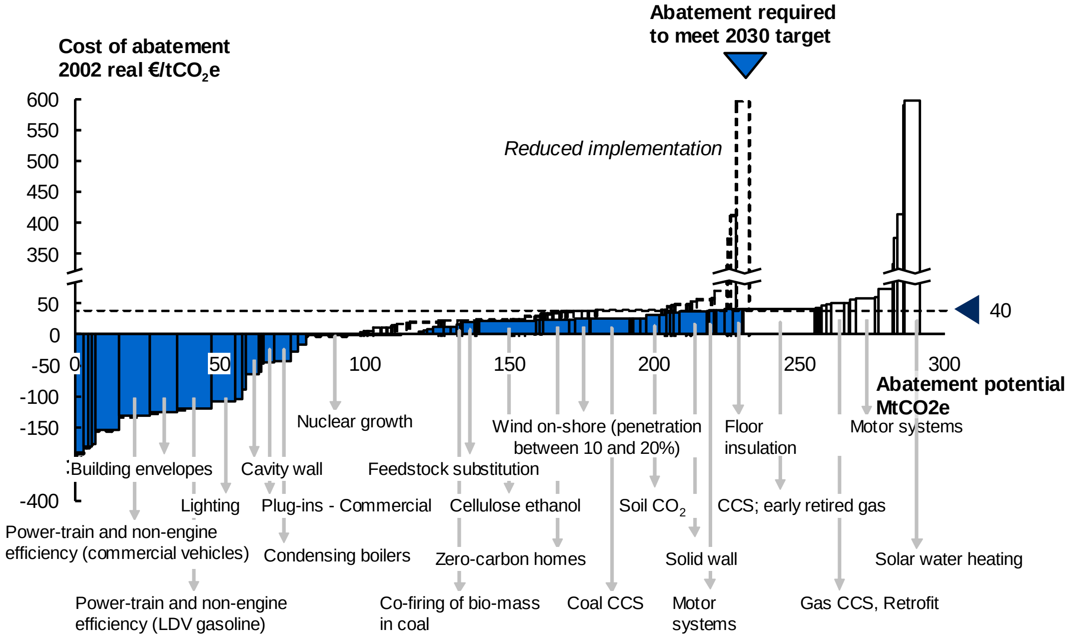

Figure 2 Cost curve for 2030. Dashed line represents reduced implementation assumptions. Meeting the implied 2030 target to be on track to 2050 is possible both in the full and reduced implementation scenarios, although with very different marginal costs. In full implementation, initiatives up to 40 €/tCO2e are needed.

By 2030, the full cost curve implies that reaching the targets of 230 MtCO2e is possible and the implied marginal cost would be approximately 40 euros/tonne. With reduced implementation rates, the 2030 target implies a significantly higher price of carbon, well above €40/t CO2e, but it would still be possible to meet the target.

The 2030 target would be met with a balanced contribution from all sectors, with similar abatement potentials from power, transport and buildings.

2.3 Sensitivity analyses

The inclusion of international transport and all greenhouse gases has only a marginal impact on these results. If we only include CO2 and exclude international transport, the required abatements are 137MtCO2e to meet the corresponding 2020 targets, as opposed to 133 MtCO2e when including all GHG and international transport. In 2030, if only CO2 is included and international marine transport and aviation are excluded, the targets imply a need for 196 MtCO2e, compared to 229 MtCO2e needed when all GHG and international bunkers are included. The implications on the marginal cost of abatement are also very small.

The conclusions are also broadly insensitive to the fuel mix used in the baseline: the baseline assumes the mix is approximately 85% gas and 15% coal. We have also run a scenario with 100% gas for new build, and one with 60% gas and 40% coal. The results are broadly similar: the marginal cost in 2030 for all these cases is around 40 euros/ton.

2.4 Implied key UK indicators

By 2030, a full implementation of all measures will have induced a reduction of 25% compared to baseline and of almost 40% compared to 1990. This means that, for example, the carbon intensity of electricity production will have to decrease from 0.42 tCO_2e/MWh to 0.14 tCO_2eMWh. It will require an increase of vehicle efficiency from the current average of 180 g/km to approximately 130 g/km by 2020 and 80 g/km by 2030. It will require buildings to increase efficiency at the rate of 1.6% per year, going from 69 kgCO2e/m2 to 44 kgCO2e/m2.

While the baseline assumes a reduction of emissions per unit GDP of 2.2% per year, full implementation to meet the targets implies a reduction of 3.5% per year. This is the result of a reduction in energy use (which in terms of energy per GDP will decrease by 2.7% per year compared to a 2% reduction in the baseline) and carbon intensity (which will decrease at the rate of 0.8% per year against a baseline of 0.2% per year). In particular, power generation per GDP will have to decrease by 2.7% per year, against a baseline reduction of 1.7% per year[3]. Finally, electricity consumption per capita, which under baseline will continue to increase at a rate of 0.4% per year, will have to fall by 0.6% per year under full implementation assumptions.

2.5 Comparison of 2020 cost curve with Energy White Paper estimates

For the 2007 Energy White Paper (EWP), the DTI calculated a cost curve for 2020. A direct comparison between that analysis and this one is not straightforward due to the difference in assumptions: The EWP cost curve shows a mixture of technologies (e.g. insulation, wind power) and policies (e.g. extension of renewable fuel transport obligation, implementation of smart meters) that imply the adoption of technologies; It also has chosen to display a lower level of detail, so that individual items on the EWP cost curve (such as “standard insulation”) represent multiple measures on our cost curve, with multiple potentials and costs. Nevertheless some comparisons are possible both on cost and potential.

For example, the EWP assumes an additional cost of nuclear of 5 £/tC (or 2 €/tCO2), close to our assumption for 2020 of 0 €/tCO2; it assumes a cost for on shore wind of 190 £/tC (or 77 €/tCO2), close to our assumption of 62 €/tCO2. More expensive items such as microgeneration are also approximately in agreement (EWP assumption for electricity microgeneration is 1,480 £/tC or 597 €/tCO2; our assumption for solar for example is 605 €/tCO2).

On the estimates of potential abatement delivered by specific technologies, the EWP and this analysis and the Energy White Paper draw on similar sources. For example EWP assumes a baseline decarbonisation of 14%, similar to that implied by this analysis of 15%. The total additional opportunities beyond baseline amount to 121 MtCO2e for the EWP and 130 MtCO2e for our analysis. The spread of opportunities across sectors is also approximately similar: the EWP assumes that energy efficiency (i.e. buildings) account for 32% of additional abatements, compared to our 36%; transport including domestic aviation is 17% compared to our 12%; ETS covered sectors would contribute approximately 47% compared to our 50%. As is implied in the EWP, we recognize the 2020 target as stretching and show that a full implementation of all measures available would be required to meet the target.

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[3] The historical reduction rate for 2000-2005 is 1.4% per year

There are however some key differences that make our analysis less optimistic with respect to meeting the 2020 targets than the White Paper appears to be. For example we have assumed that CCS will only become commercially available after 2020. While it is possible that it will become commercially viable before then, at this time the balance of evidence suggests this is unlikely. It is critical that the government accelerate demonstration projects to ensure the measure is commercially available as soon as possible. Unlike the EWP, we do not assume that wind potential will be fully exploited to meet the renewables obligation targets as a matter of baseline. We believe this is an additional abatement that will require additional efforts, including a reform of the planning system and overcoming high costs. Although we have included a number of gateways towards zero-carbon homes, we do not currently believe that zero carbon homes should be included in a baseline scenario, and will require additional effort. The single biggest additional measure in terms of impact advertised by the EWP is a successor to EU-ETS. But it should be noted that the marginal price implied by our cost curve to meet the 2020 target is high compared (60-90 €/ton) to historical and expected future prices.

2.6 Total cost To calculate a credible estimate of the total potential cost of implementing all abatement levers in a given year, it is not sufficient to simply add up the costs along the cost curve. The reason is that the cost curve represents only the technological cost and does not take into consideration transactional costs (e.g. the management time needed to implement an initiative, the costs involved in raising awareness, the costs in overcoming high discount rates, etc.) which may add to the overall cost of implementation. Other, more subtle effects are also not taken into consideration, such as opportunity costs of choosing abatement measures over other investments, as well as broader effects on the economy. Despite these difficulties, an estimate of cost can be made by assuming that:

1. The actual cost of implementation of the negative-cost abatement initiatives is equivalent to their net benefit to society. This is equivalent to assuming that all hidden costs will amount to no more than the net benefit resulting from implementing the initative.

2. For all cost-positive abatement initiatives there are no additional implementation costs beyond those captured in the cost curve and we can apply a weighted average cost. For each abatement, we apply the 2020 cost to the portion of abatement installed by 2020, while we apply the 2030 cost to the portion of abatement installed between 2020 and 2030. This estimate assumes that the cost in one year is representative of the cost for the decade, but the resulting error is subsumed in the broader approximation.

3. The total cost of implementing the full abatement in 2030 is the sum of all costs estimated in this way. This provides an estimate of the cost of implementation that we think is likely to capture the size of the challenge. In 2030 the UK will need approximately 230 MtCO2e of additional abatement compared to baseline in order to meet its targets. Approximately 130 MtCO2 could be achieved by 2020. The remaining 100 MtCO2 could be achieved by 2030. An estimate of the cost of the implementation is then approximately € 3.6 billion per year. This is equivalent to £2.5 billion, or assuming 25 million households, approximately £100 per household.

3. The baseline

Baseline emissions already represent a large reduction in emissions compared to what would happen in the absence of any improvement in technology. These "expected" improvements represent a significant contribution made towards emissions reduction by all sectors in the UK. Baseline emissions are however still too high to meet the UK targets.

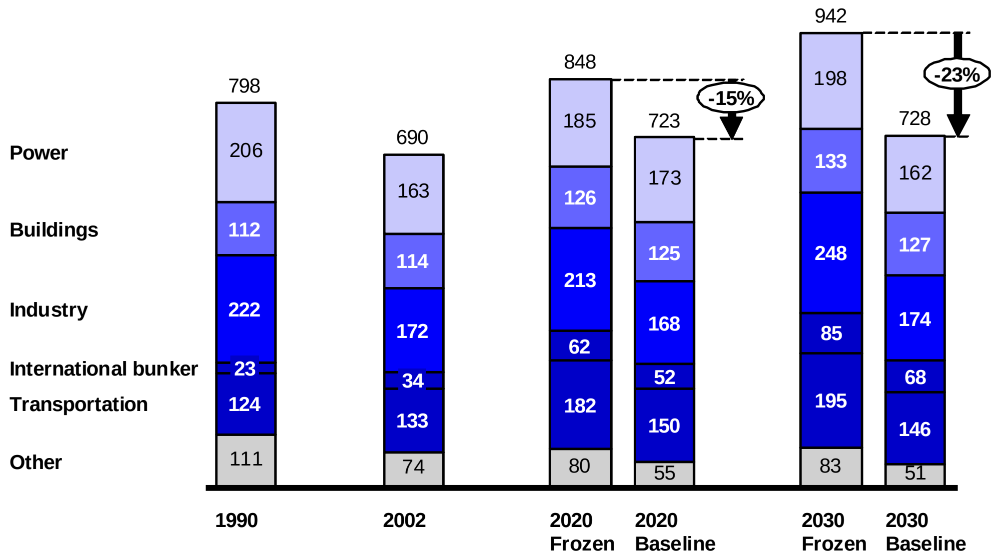

Figure 3 UK emissions for 1990, 2002 (reference year for this analysis), 2020 and 2030. Frozen technology and baseline emissions are shown for both 2020 and 2030, to emphasize the significance of ongoing efforts to reduce emissions.

UK emissions decreased steadily from almost 800 MtCO2e in 1990 to 690 MtCO2e in 2002, due primarily to the switch from coal to gas in the power sector and to de-industrialization[4]. In recent years however this trend has changed and emissions have started to grow again, driven primarily by increases in transport and power use[5]. Four sectors accounted for the 90% of the 690 MtCO2e emitted in 2002: power generation (24%), industry (25%), transport (24%), and buildings (17%). The remaining 10% is due to agriculture, waste, and land use[6] and are not the focus of this analysis.

The construction of a baseline requires two steps: 1) estimating how emissions would evolve in the future if technology were "frozen" to today's state; 2) estimating the impact of expected improvements. The latter, referred to as *decarbonisation*, mitigates the impact of the increase in demand driving the former and represents the on-going efforts to reduce emissions.

The underlying drivers for the increase in emissions are GDP (assumed to grow at 2.4% CAGR) and population (assumed to grow at 0.4%). However, each sector is driven by specific assumptions as outlined below. The economics of the baseline are also very important as they determine the size of the relative cost of the additional abatements. In particular, fuel prices are a major factor in the economics. For the purposes of this

[4] 2006 Climate Change Programme

[5] Ibid.

[6] IPCC, Team analysis

analysis, the price of coal, gas, and oil were taken from DTI projections, even though those estimates may currently appear conservative.

3.1 Power baseline

In 2002, emissions from power generation were 163 MtCO2e[7]. Frozen technology growth in power generation is driven by constant fuel mix and emission intensity and projected growth in demand for power. Under these assumptions, the frozen technology baseline is expected to grow over 20%, bringing emissions from power generation to 198 MtCO2e by 2030.

The decarbonisation of the power sector is driven by planned plant builds and closures up to 2015[8] and subsequent estimates, including a fuel shift as well as the substitution of higher efficiency plants in place of the older ones. The shift in fuel mix contributes a reduction of 25 MtCO2e and is driven by: *a decrease in nuclear plants*, which decreases from 23% of generated power[9] to 2% as all but one existing plants are retired; *a decrease in conventional coal plants*, from 33% in 2002 to 11% in 2030; *an increase in gas plants* from 40% in 2002 to 79% in 2030; *an increase in wind and other renewables* from less than 2% in 2002 to almost 7% in 2030. The high concentration of gas in the final fuel mix is based on the assumption that the current trend towards gas build continues[10]. The substitution of new, more efficient gas and coal plants in place of the old ones will contribute another 11 MtCO2e reduction: the carbon intensity of gas is expected to decrease, due to improved efficiency in turbines used to generate electricity[11].

As a result of the balance between increased demand and decarbonisation, the baseline in power generation is assumed to stay approximately stable in the baseline scenario, going from 163 MtCO2e in 2002 to 162 MtCO2e in 2030. The baseline is obviously sensitive to a number of assumptions, not least the cost of fuel which determines the economics of gas and coal plants. Gas in particular is sensitive to the price of fuel as it is a larger component of its cost[12].

3.2 Transport baseline

Transport emissions in 2002 accounted for 167 MtCO2e and are divided by emissions due to domestic transport (75%), which is overwhelmingly dominated by road transport, and emissions due to international bunkers (25%), which include marine and international aviation.

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[7] Of these, 63% were due to coal, 33% to natural gas, and 4% to oil. Given utilisation rates and efficiency of conventional plants, coal was responsible for 33% of the total 385 TWh of electricity produced, while gas accounted for almost 40%. The remaining power generation was due to existing nuclear plants (23%), oil and renewables

[8] Powervision by Platts for plant forecasts; global insight growth rate

[9] We focus on generated power as opposed to installed capacity, which would not reflect utilization rates

[10] In time, this may imply the need for additional infrastructure such as additional LNG terminals.

[11] Carbon intensity for gas is expected to decrease from 0.35 MtCO2e/TWh in 2002 to 0.32 MtCO2e/TWh in 2030, while that of coal will decrease from 0.76MtCO2e/TWh in 2002 to 0.67 MtCO2e/TWh in 2030

[12] The reference cost for the baseline mixture of coal and gas (84% gas, 16% coal) is approximately 95 euros/MWh in 2010 and 92.5 euros/MWh in 2030.

The increase in emissions from domestic transport under frozen technology assumptions is driven by an increase in passenger miles, assumed to grow 1.4% CAGR overall[13]. Growth is dependent on vehicle type and use, with the highest growth shown by light goods vehicles, followed by cars and taxis and goods vehicles heavier than 3.5t. This growth increases the frozen technology scenario to 195 MtCO2e emissions for the domestic sector by 2030.

The demand driven increase is offset by ongoing power-train and non-engine improvements, which are expected to lead to efficiency improvements of 20% on light duty vehicles (LDV) fuelled by petrol, 13% on LDV fuelled by diesel and 17% on commercial vehicles[14] [15]. It is also assumed that hybrids will reach a penetration of 10% by 2030, while the impact of plug-ins will be negligible under baseline conditions. The penetration of hybrids is somewhat limited by the fact that, while the cost decreases in time, the efficiency improvements in regular vehicles make the economics of a hybrid less advantageous. It was also assumed that UK and EU targets for bio-fuels would be met with a mixture of local and imported bio-fuels: 5% penetration by 2010, with one third imported sugarcane ethanol; 10% penetration by 2020, with two thirds imported sugarcane. That penetration is then assumed constant up to 2030. The sum of these effects reduces the projected growth by 49 MtCO2e, so that the baseline for domestic transport increases from 133 in 2020 to 146 in 2030.

International transport emissions were responsible for 34 MtCO2e in 2002 and under frozen technology assumptions are expected to grow faster than domestic transport emissions, to 84 MtCO2e by 2030. This growth is driven by a 3.3% growth in million passengers per year (from 185m passengers in 2002 to 465m by 2030[16].) Decarbonisation is expected to be significant, following consistent historical improvements. Initiatives such as ACARE[17] programs and the economics of fuel efficiency, a fundamental driver for airline costs, have resulted in significant efficiency gains which are assumed to continue: an improvement of 1.3% CAGR is expected for the decade up to 2010, followed by improvements of 1% per year in the decade 2010-2020 and 0.5% in the following decade up to 2030. The resulting decarbonisation reduces baseline emissions by 16 MtCO2e bringing the baseline down to 68MtCO2e in 2030. The decarbonisation in this case is driven primarily by improvement in engine and aircraft efficiency (e.g., reduced weight and drag), with some efficiency gains from streamlined air traffic management.

3.3 Buildings baseline

The buildings sector in 2002 emitted directly 114 MtCO2e, divided into residential buildings (71%) and commercial buildings (29%). Under frozen technology, emissions are expected to increase by 19 MtCO2e by 2030, driven primarily by an increase in floor

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[13] 2% in the decade to 2010, 1.6 in the decade 2010-2020, 0.7% in the decade up to 2030. Figures from European Commission projections for growth of passenger km in the UK. Trends are broadly consistent with the historic data and near-term predictions provided by the DfT

[14] LDV = Light Duty Vehicle

[15] An additional large source of improvement could be the switch between vehicle types, but the potential was not quantified as it was assumed to rest on purely behavioural and consumer choice grounds

[16] The estimate takes into account some constraints on airport planned extensions and likely improvements in the UK.

[17] Advisory Council for Aeronautic Research in Europe

space[18]. This is equivalent to an increase in number of households of over 4 million, from 24 million in 2002 to 28.5 million in 2030. The growth is net and takes into account existing stock, expected new-build and expected demolition rates. Energy consumption also increases by 21% between 2002 and 2030, but emissions only grow by 7% due to a reduced carbon intensity of electricity as well as a reduced reliance on coal and oil. Indirect emissions from electricity use were already included in the power baseline, even though they are affected by measures taken in the buildings sector.

The decarbonisation of buildings is small, accounting for 6 MtCO2e of reduced emissions driven by tightening regulations in housing and appliances. The baseline assumes that by 2006, new build was 40% more efficient than legacy stock, from 2010 new build will be 25% more efficient than 2006, and by 2013 new build will be 44% more efficient than 2006[19]. Zero carbon homes are not included in the baseline, as they are not yet in the statute and a clear definition is missing. They are however included in the additional abatements below.

3.4 Industry baseline

Industry emissions in 2002 were 172 MtCO2e and are divided into direct emissions from manufacturing and construction industries (51%), energy industries such as petroleum refining and solid fuels (22%), industrial processes (16%) and fugitive emissions (11%). Emissions were projected to grow following the growth of industrial gross value added to 248 MtCO2e[20]. Indirect emissions for the industry sector were estimated based on electricity consumption[21], also estimated to grow based on gross value added growth, and multiplied by the baseline power generation carbon intensity. As was the case with indirect emissions from buildings, indirect emissions due to electricity consumption in various industrial sectors were included in the power baseline.

Decarbonisation is expected to be 74 MtCO2e by 2030, reducing the emissions to 174MtCO2e. Reduction in carbon intensity of the industrial sector was assumed to follow the OECD baseline rate of decarbonisation and was scaled accordingly. The decarbonisation is based on an expected annual efficiency improvement of 1.5% for CO2 emissions. For non-CO2 emissions, a reduction in growth of 1% was assumed for manufacturing industries which include semiconductor manufacturing, refrigeration/air conditioning and others, while no efficiency gains were expected for energy industries, including biomass combustion, oil production, coal mining, and natural gas systems.

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[18] Increase of floor space is 4% over 2002 by 2010, 10% by 2020 and 16% by 2030. DTI planning projections; BRE; DCLG table 401, and English House Condition Survey, Residential Floor Space 2004

[19] These estimates are in line with a number of published sources, including Carbon Trust, Building Regulations Part L, 2006, DCLG targets (reaching Code level 3 by 2010, 4 by 2013); BRE; DTI planning projections

[20] Estimate Global Insight, World Industry Monitor

[21] Estimates from IEA sector consumption for the UK

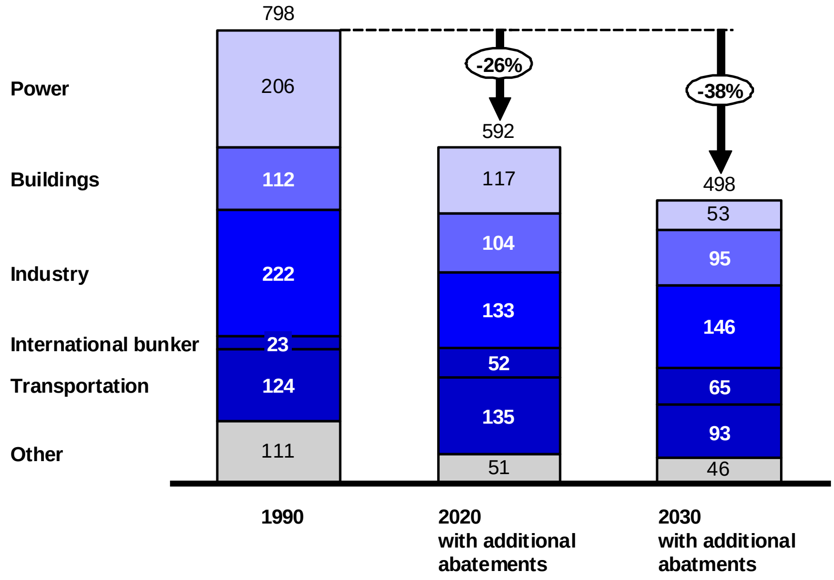

Figure 4 Emissions after abatements for 2020 and 2030, compared to total emissions in 1990. Each sector contributes reductions.

3.5 Other sectors baseline

Agriculture, forestry, and waste are not modelled bottom-up, but are scaled from the OECD cost curve. Emissions from agriculture and waste are assumed to grow with the population for frozen technology, while forestry and land use are scaled according to the historic change in stock between 1990 and 2005.

4. Additional abatement potentials by sector

By 2020 buildings and industry will contribute the biggest abatements, and emissions could be reduced by up to 26% compared to 1990 levels. By 2030, all sectors contribute a similar share of the abatement potential and emissions could be reduced by almost 40% compared to 1990 levels.

4.1 UK targets

The UK has committed to a reduction of 26-32% by 2020 and of 60% by 2050 from 1990 emissions levels[22].

A high level analysis shows how those targets compare to current performance of other peer countries. If we restrict ourselves to carbon, CO2 emissions are a function of the energy intensity of the economy and of the carbon intensity of the primary energy used. Currently, the energy intensity of the UK economy is 0.15 toe/thousand - 2000 US$[23].

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22 The UK has committed to a reduction of emissions of CO2, but we apply the targets to all GHG. A review of the sensitivity to this assumption is shown below

23 2004 IEA energy statistics

Comparing this energy intensity to that of peer countries such as Germany (0.18), France (0.19), USA (0.22) and Holland (0.21) shows that the energy intensity of the UK is in line with other major developed countries. However, a lower energy intensity is possible, as demonstrated by the case of Japan (0.11 toe/thousand - 2000 US$)[24]. The carbon intensity of the UK total primary energy supply (2.30 tCO2/toe) is also in line with that of other peer countries, such as Japan (2.28 tCO2/toe), Germany (2.44), Holland (2.26) and USA (2.49). However countries with significantly different fuel mix in their generating capacity can have much lower carbon intensity, such as France (1.41 tCO2/toe) and Norway (1.31 tCO2/toe). It is worth pointing out that, should a country like the UK achieve the energy efficiency of Japan, and carbon intensity similar to that of France or Norway, it would reduce the carbon intensity of its economy by over 50%. While this would be offset by the growth in real GDP, the fact that existing economies are able to achieve the energy and carbon intensities broadly required by the government targets suggests that the transformation is, at least in principle, achievable.

If we apply the reduction levels implied by the targets to all greenhouse gases and not just CO2, they imply that the UK will have to emit no more than 590 MtCO2e by 2020 and - assuming a linear decrease to 2050 - no more than 500 MtCO2e by 2030. Given the baseline scenario illustrated above this will require 133MtCO2e abatements by 2020 to reduce the 723MtCO2e baseline, and 230 MtCO2e by 2030 to reduce the 730 MtCO2e baseline. Each of the main emitting sectors has the potential to contribute to these reductions. Following are some of the main areas of reduction for each sector.

4.2 Additional abatements in power

The total additional reduction in emissions from power generation achievable by 2030 amounts to 107 MtCO2e. This is divided into a contribution of 45 MtCO2e from demand reduction in buildings and industry, and 64 MtCO2e from a reduction in the carbon intensity of power generation. Reductions in demand from buildings (80%) and industry (20%) are described in the relevant sections below. The key drivers for the reduction in carbon intensity are the replacement of coal/gas new builds with alternative generating assets such as wind, nuclear and carbon capture and storage (CCS) applied to coal plants. Abatements are assumed to take place when the existing generation capacity is expected to retire. Additionally, abatements could arise, once the capital cost of existing plants is fully amortized, by early retirement of existing plants, which are then replaced with alternative generation. This is assumed to be possible during the decade 2020-2030 for all plants built before 2002.

Wind is assumed to reach ~17% of generation mix given a potential government target of 20% renewables by 2020, with a split of 50% onshore and 50% offshore. This assumes that subsidies will allow the uptake of off-shore despite higher costs[25]. While the UK has a large wind asset, we have assumed a limit to the penetration of wind because of the economics of intermittency costs: up to a penetration of approximately 15% these costs are relatively low, as wind can provide the marginal generation above maximum capacity;

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[24] IEA energy statistics, 2004. Numbers should be taken as indicative as the energy intensity varies with the industrial base. Japan is however significantly more energy efficient than most other countries (See for example, McKinsey Global Institute, "Productivity of growing energy demand: a microeconomic perspective")

[25] Onshore wind will cost 111€/MWh in 2010 and 95€/MWh in 2030. Offshore wind will be more expensive at 135€/MWh in 2010 and 114€/MWh in 2030. However intermittency costs significantly increase the overall costs, at 6€/MWh for wind generation up to 10% of total generation capacity, and 14€/MWh for wind generation between 10% and 20% of total generation capacity

for higher penetration, backup generation is necessary to ensure supply at times of maximum demand, which in turn raises costs.[26]

There are multiple uncertainties about when Carbon, Capture, and Storage (CCS) will be commercially available and at what cost. While some argue for commercialization before 2020, we have assumed that it will take up to 2020 before commercial plants are commercially available. After that, we assume a linear uptake up to 100% of new plants by 2025. After 2025, we assume 100% penetration of CCS in new build. Of the 49 MtCO2e additional abatements available from CCS[27], 28 come from early retirements of coal CCS, 15 from new build coal, and 6 from gas CCS retrofit. The cost of new coal CCS is lower than gas, making it the preferred technology. The application of CCS is assumed to capture 85% of emissions and result in a 20% decrease in efficiency. Storage is assumed to not be a limiting factor and transport and storage costs are assumed to be 10 €/tCO2.

As of 2018[28], nuclear power is assumed to be the preferred technology due to lower cost compared to both wind and CCS, but with a limited ramp-up of 1 GW per annum. It is assumed that new nuclear will only be built on existing sites, and that up to two reactors of 1 – 1.6 GW capacity per site can be built. Decommissioning costs are included in the estimate of cost. They are considerable, but when amortized over the 40 year lifetime of a plant, they do not amount to more than 5% of total cost.

4.3 Additional abatements in transport

Abatements in the domestic transport sector rely primarily on fuel efficient technologies and biofuels. Fuel efficient technologies are already a significant component of the baseline, but can deliver up to 29 MtCO2e in additional abatements by 2030. The initiatives include power train measures such as start-stop systems, transmission improvements, thermo management, and inner engine measures such as turbo charging, direct injection, variable valve lift and timing, cylinder deactivation, camless valve actuation and variable compression ratio. They also include non-engine initiatives such as improved aerodynamics, light weighting, and rolling resistance. Most of these initiatives individually have an impact of under 10% on fuel consumption, but they collectively can produce significant improvements. Of course applicability depends on model and end use: if we include baseline improvements, by 2030 light duty gasoline vehicles will be 44% more efficient, and light duty diesel vehicles will be approximately 32% more efficient, as diesel is already a relatively efficient engine[29].

Despite considerable uncertainty, we estimate biofuels could reduce emissions by up to 20 MtCO2e. Biodiesel is expected to be limited to the penetration already included in the baseline (UK and EU 2010 and 2020 targets of 5% and 10%) due to engine technology constraints. With current levels of air pollution constraints, typical existing filters could not operate on more than a 10% biodiesel mix. By 2010, potential for ethanol is at 10%

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[26] In continental Europe such costs are often mitigated by the interconnection between countries, which allows for backup generation to be provided through the market. Britain cannot rely on this mechanism beyond the existing interconnector with France, which is already almost at capacity. We have also assumed that plants are only built when new demand arises or when old plants retire, which prevents us from assuming that a burst in deployment could take advantage of scale and reduce the backup costs per plant

[27] Only new coal CCS plants are under 40 euros/ton CO_2e

[28] Assuming planning, decommissioning, and waste management problems are resolved now, certification and construction would take up to 10 years, delivering the first nuclear power station in 2018

[29] McKinsey Drive Study

penetration, in line with fleet ability to absorb E10. It is assumed that between 2010 and 2020 no additional penetration is possible due to the inability to exceed 10% with current fleet. Ethanol could reach 50% of gasoline mix by 2030, however infrastructure changes may be needed depending on technology, which adds to the uncertainty. Costs and impact potential also vary widely depending on the type of biofuel involved: biodiesel has a well-to-wheel CO2 intensity that is 20-50% that of reference fuel, depending on feedstock; grain ethanol is approximately 70%, while sugarcane and cellulose ethanol are both approximately 10% of reference fuel. The reduction in cost of these technologies varies widely depending on circumstances. For example biodiesel is expected to decrease only from 0.47 to 0.41 €/lit in 2030, while the cost of cellulose ethanol is expected to decrease from 0.5 to 0.26 €/lit in 2030. Furthermore, these costs fail to take fully into account the potential impact of international tariffs which can distort the pricing of biofuels depending on origin.

For international bunker, principally aviation, most of the improvements are expected to occur as baseline given the economics of the airline industry, where fuel costs can make up to 30% of operating costs. Incremental abatements could be achieved if airlines are provided with incentives equivalent to a carbon tax of 40 EUR/tCO_2, primarily through faster fleet replacement and incremental technology such as winglets retrofits. More radical technologies have not been considered given the timescale required to move them from prototype to commercial scale, and given the current state of most existing prototypes.

4.4 Additional abatements in buildings

For residential buildings up to 18 MtCO2e can be saved from solid wall insulation, cavity wall insulation, loft insulation, heating controls, and by turning homes to zero carbon. Given the low turnover of the housing stock in the UK[30], most initiative will have to be retrofitted in existing buildings. The cost and applicability of these initiatives varies widely depending on the building[31], going from loft insulation, which is applicable to roughly 15 million units and has an upfront cost of approximately £150, to solid wall insulation, applicable to half that number and with an upfront cost of over £2,000. Assuming a real discount rate of 7%, all these initiatives are efficiency initiatives that pay back within the given timeframe. Given the age of the stock, retrofit initiatives have a large potential, but critically depend on consumer uptake.

Efficient appliances can also save up to 5 MtCO2e in direct emissions, primarily from condensing boilers, which by 2030 are assumed to be in all buildings that have a gas boiler. Zero carbon homes are assumed to be 100% of new build from 2016, over the baseline scenario. Every year roughly 180,000 new homes are built, although it should be noted that the cost of building zero carbon homes is significantly higher (~£15,000) than level 4 homes.[32] Zero carbon homes include improved insulation, onsite electricity generation (e.g., solid biomass, micro wind, micro solar, housing development generation). The potential to 2030 is limited by the turnover rate, although it is expected that the impact will be larger after 2030, which is beyond the scope of this analysis.

Commercial buildings can reduce direct emissions by up to 8 MtCO2e from improving the building shell, heating and cooling technologies, energy management systems, and, to a

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30 New build represents 0.75% of the stock, and ~3% of existing stock is renovated in any given year

31 For further reference, BRE cost curve report: Reducing carbon emissions from the UK housing stock, 2005, prepared for DEFRA

32 A 30% improvement in cost is assumed by 2030

lesser extent, from solar heating and cooling and district heating and cooling systems. Savings from water heating can contribute up to 2 MtCO2e.

Indirect emissions in buildings associated with electricity consumption can also be substantially reduced through efficiency measures. For residential buildings the measures described above can save up to 8 MtCO2e in indirect emissions, while efficient lighting, reduced stand-by losses, efficient washing and drying, condensing boilers, efficient refrigerators, AC and efficiencies on other appliances such as computers and TV screens, can add up to 16 MtCO2e. For lighting we assume the government will ban incandescent light bulbs from 2009. For other appliances it is assumed that by 2030 there will be efficiency gains of 33% (varying by appliance, e.g., 7% for dishwashers, 61% for tumble driers), with 1 Watt maximum stand-by losses in new appliances with a 75% implementation rate (current average is closer to 7 Watts).

In commercial buildings improvements to the building shell can reduce indirect emissions by up to 2MtCO2e, while efficient appliances such as AC, lighting and water heating can reduce indirect emissions by up to 10MtCO2e[33].

4.5 Additional abatements in industry

The total direct abatements available from industry amount to 28 MtCO2e. The industrial sector is very fragmented, and estimates for most initiatives had to be made top-down. Direct abatement opportunities are mainly for non-CO2 emissions, with 14 MtCO2e coming from reductions in industrial and energy production, 6 MtCO2e from fuel substitutions and efficiencies, 5 MtCO2e from feedstock substitutions, and 3 MtCO2e from the applications of carbon capture and storage (CCS) to industrial processes. Non CO2 abatements include, amongst others, refrigeration recovery, changes in solvent use (e.g., HFC to HFE), catalytic reduction methods for nitric acids, thermal oxidation for HCFC-22, electric power systems for recycling and leak detection and improvements in energy production (e.g., degasification, catalytic oxidation, flaming in coal mining; replacement of high-bleed pneumatic devices, dry seals on centrifugal compressors, reinjection, etc.)

There were also an additional 9 MtCO2e in power demand reduction. These indirect abatements come mainly from improved motor system efficiencies (6 MtCO2e) and, to a lesser degree, from energy efficiency in materials production (1 MtCO2e) and CHP (1 MtCO2e). Variable speed drive replacements are negative cost opportunities, applied to pumps, fans, air compressors, cooling compressors.

[33] Opportunities in commercial buildings are scaled from IEA estimates assuming the UK is not significantly different from the rest of the EU