THE NEW CLIMATE ECONOMY
The Global Commission on the Economy and Climate

Technical Note

Emission Reduction Potential

NEW CLIMATE ECONOMY PROJECT

CONTENTS

Disclaimer

This paper was compiled by New Climate Economy (NCE) staff as part of the research conducted for the Global Commission on the Economy and Climate, and expands on selected topics in the Commission's main report, *Better Growth, Better Climate*. The New Climate Economy project is pleased to publish it as part of its commitment to provide further evidence on and stimulate debate about the issues covered in the report.

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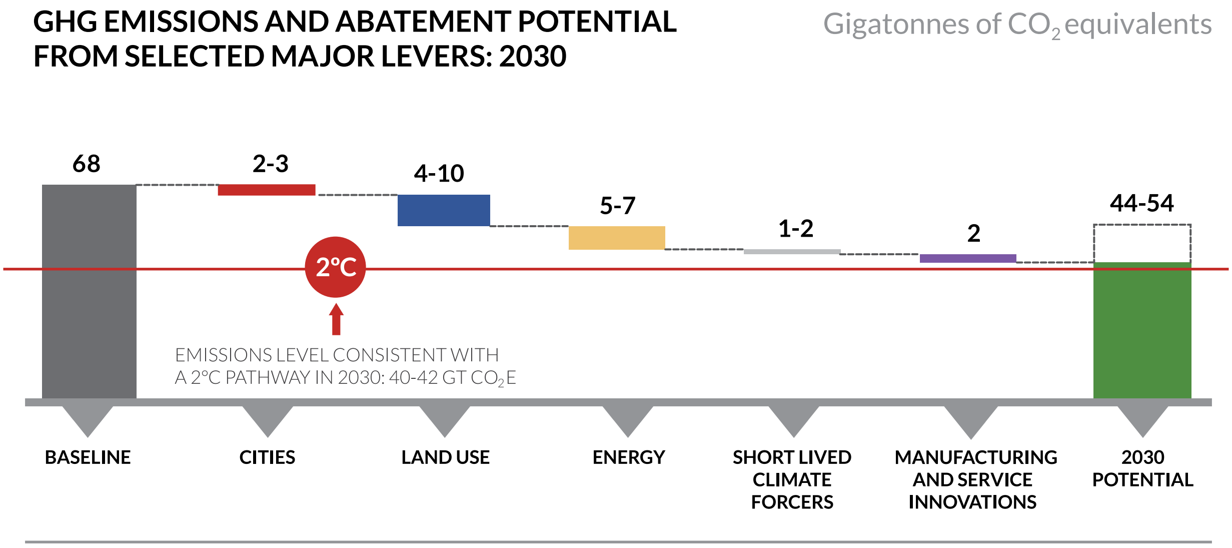
1. INTRODUCTION

The New Climate Economy project has estimated the extent of greenhouse gas (GHG) emission reductions that could result by 2030 from undertaking some of the measures and actions discussed in the Commission's report. The measures selected for analysis, and recommended by the Global Commission, are ones that would bring not only climate benefits, but also multiple economic and social benefits. In many cases, the measures have the potential to achieve net benefits (understood broadly) even before considering climate benefits. As shown in Figure 1, we estimate the potential emission reductions of undertaking these measures at 14–24 billion tonnes of carbon dioxide equivalent (Gt CO_2e). This would narrow the gap between a baseline emissions pathway and one compatible with a two-thirds chance of keeping global average warming below 2°C by at least 50% in 2030, and potentially by as much as 90%. The range is large, reflecting uncertainties about the feasible rate of implementation and the conditions that influence future emissions levels, as well as costs and benefits.

This note summarises the analysis and assumptions underlying the emission reduction estimates, including the principles, scope and limitations of the analysis.

Figure 1: Actions with economic benefits could deliver most of the abatement needed for 2030 targets



SPECIFIC ACTIONS AND MEASURES:

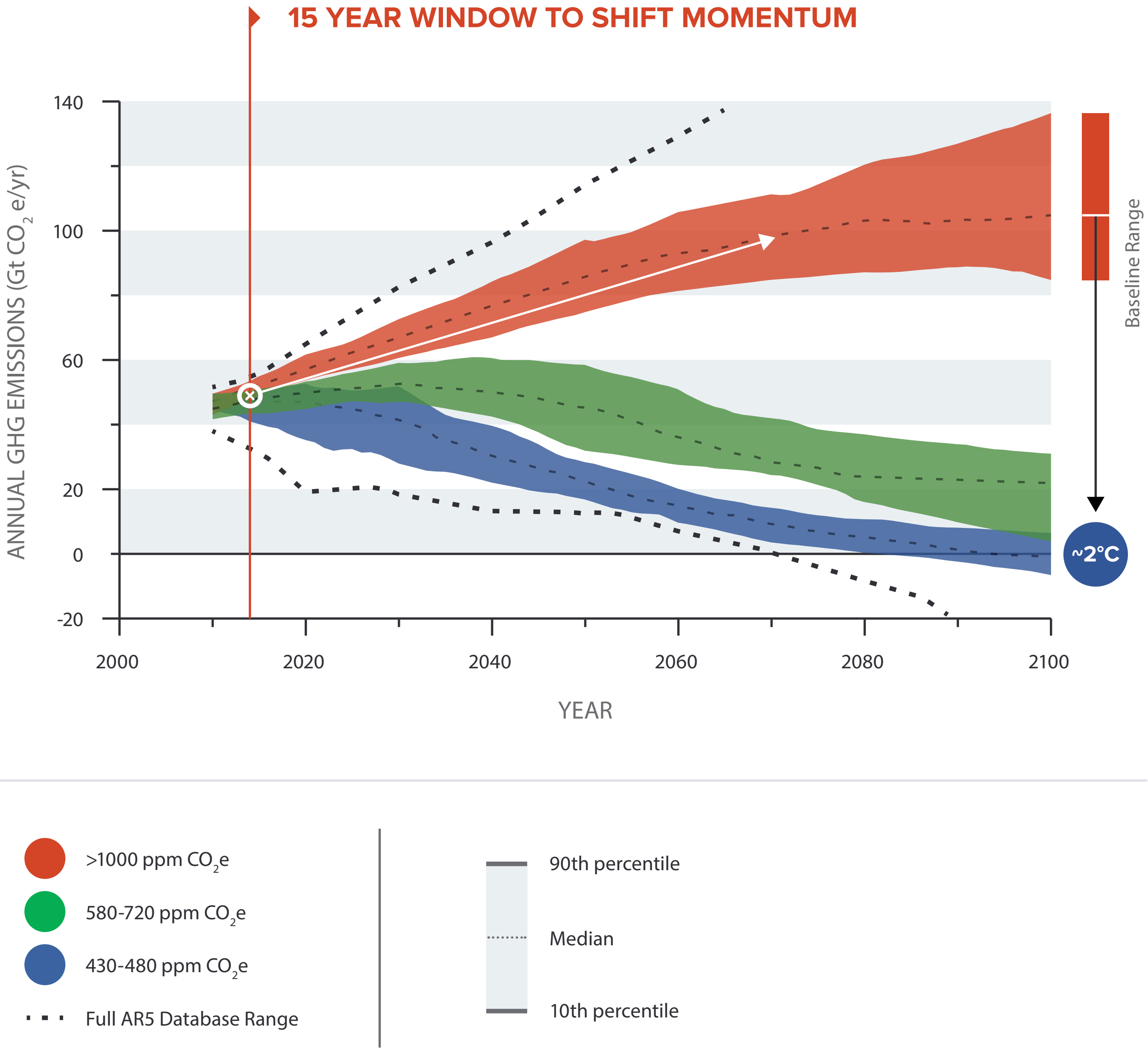
CITIES	LAND USE	ENERGY	SHORT-LIVED CLIMATE POLLUTANTS	MANUFACTURING AND SERVICE INNOVATIONS
• More compact urban form, with greater use of mass transport, and deployment of urban technologies (new & existing)	• Improve agricultural productivity • Halt deforestation • Restore degraded land • Reduce food waste	• Remove fossil fuel subsidies • Transition away from coal • Reduce methane emissions from oil & gas	• Reduce HFCs through regulation	• Application of digital technologies to enhance efficiency of manufacturing and services

STRONG CARBON PRICING AND AN EFFECTIVE INTERNATIONAL CLIMATE AGREEMENT WILL HELP TO DRIVE ALL LEVERS

2. APPROACH AND METHODOLOGY

We chose as a baseline value for 2030 emissions the median value in the range of baseline emission projections considered by the Intergovernmental Panel on Climate Change (IPCC) in its latest review.[1] Emissions today are about 50 Gt CO_2e; for 2030, the median baseline projection is 68 Gt CO_2e. The IPCC further collates a range of emissions pathways that could correspond with a likely (more than two-thirds) chance of holding the average global temperature rise to 2°C; the median value for 2030 is 42 Gt CO_2e.[2] There is considerable uncertainty about future GHG emissions; hence the range of projections.[3] Figure 2, adapted from an IPCC figure, highlights the median values for 2030.[4] Based on this, we take 26 Gt CO_2e as a benchmark level of the emissions reductions needed in 2030 to bridge the gap between the baseline and a pathway consistent with a 2°C target.[5]

Figure 2: Baseline emissions and target emissions for 2030



Source: Adapted from IPCC, 2014, Figure SPM.4.[6]

Analyses of future emissions pathways, such as those surveyed by the IPCC, typically use integrated models of the energy system and other parts of the economy, often over timespans extending as far as 2100. While individual scenarios can differ significantly, such low-emissions pathways share common features. These include a sharp reduction in the energy intensity of the economy, a broad portfolio of new low-carbon energy sources across sectors, rapid reductions in CO_2 emissions from electricity production, and a sufficient shift to electrification and/or other energy carriers in the transport sector to stop the growth in oil product use within the next two decades.[7] Many also include significant changes to land use patterns, and some degree of carbon capture and storage (CCS) applied to future electricity and industrial emissions. Achieving these outcomes, in turn, requires a broad range of changes to investment patterns and end-use patterns across sectors and geographies.

The analysis presented here has a different starting point. It starts not from an emissions end-goal, but from a set of concrete actions identified in the Commission's work as having significant near-term potential for multiple benefits, as well as for substantial emissions reductions. It is thus a bottom-up assessment rooted in areas with potential for near-term action and linked to the Commission's recommendations. It does not cover the full range of actions and transformation that would be required to achieve a 2°C pathway. We do find a significant overlap with those actions, and specifically that there is substantial abatement potential in terms of 2030 annual emissions levels. However, whether a particular annual level and composition of GHG emissions in 2030 is ultimately consistent with a 2°C pathway depends on many factors, not least how emissions develop thereafter (some models suggest that emissions would need to be net negative in the second half of this century).[8] In addition, emissions can decline in a given period even as infrastructure investments are being made that could make future reductions more difficult – which would thus result in high future cumulative emissions. This analysis does not model such lock-in and its implications beyond 2030.

The measures and actions set out in Figure 1 cover cities, land use change, energy, and specific forms of innovation and process changes in manufacturing and services. The main New Climate Economy report, *Better Growth, Better Climate*, discusses these at much greater length, including their potential to have multiple benefits and their potential to contribute to higher-quality growth. As outlined in the main NCE report, higher-quality growth is defined by the Commission as growth that: is inclusive (in the sense of distributing its rewards widely, particularly to the poorest); builds resilience; strengthens local communities and increases their economic freedom; improves quality of life in a variety of ways, from improvements in health as a result of better air quality, to reduced commuting times due to lower urban traffic congestion; and sustains the natural environment by protecting or enhancing ecosystem services. While we do discuss the costs and benefits of each of the measures briefly here, this note should therefore be read in conjunction with the main NCE report.

The estimates of emissions abatement potential and costs and benefits are based on existing literature, new research commissioned for NCE, and NCE staff estimates based on consultations with experts. There are many uncertain factors that affect the analysis – from technical aspects, to uncertainties about valuations and prices that affect costs and benefits, to the feasible pace and extent of implementation given the significant barriers in place in some cases. Given those uncertainties, our estimates cannot be precise, and we give wide ranges in each case, reflecting ranges from the literature where available. The high end of the range typically would require early, broad and ambitious implementation, with decisive policy change and leadership, rapid learning and sharing of best practices, and strong international cooperation.

Our analysis has some additional limitations:

- Baseline estimates: This analysis collates multiple separate analyses, which means that underlying assumptions differ in some cases. Important examples include future baseline emissions and assumptions about the costs of key technologies and inputs. We have attempted to draw on comparable scenarios to the extent possible, but in some cases have had to reflect the uncertainty by giving a wider range of possible future emissions levels.
- Interactions between measures: In some cases, the different categories of actions analysed here potentially act on the same underlying emissions. We avoid the double-counting of emissions reductions by subtracting any emissions reductions that are already covered in other calculations. We have erred on the side of caution by assuming complete overlap between different measures, even where detailed modelling might well indicate that the overlap would be more limited.
- Consideration of wider impacts: Integrated models of emissions abatement have identified important knock-on impacts of measures that reduce emissions. Examples include "rebound" effects, whereby economic activity can increase as a result of productivity improvements (e.g. increased energy consumption as a result of higher energy efficiency), and changes in relative fuel prices in response to changing energy consumption patterns. Our analysis does not model these impacts directly, but where possible we have attempted to account for existing estimates of their significance and adjust our estimates accordingly.

3. ASSESSMENT OF ABATEMENT POTENTIAL

As summarised in Figure 1, abatement potential estimates are provided for 10 categories of action in five sectors:

A. Cities

1. Shift to compact, connected urban growth with greater use of energy-efficient transport and reduced energy use in buildings, plus deployment of existing and new urban technologies to improve resource productivity

B. Land use

2. Greater use of agricultural management measures that improve yields and reduce emissions
3. Halting of net deforestation
4. Restoration of degraded land
5. Reduced food waste

C. Energy

6. Reduced coal use through improved energy efficiency and transition to lower-carbon sources of energy
7. Reduced fugitive methane emissions from the oil and gas sector
8. Removal of fossil fuel subsidies

D. Short-lived climate pollutants

9. Phasing out of hydrofluorocarbons (HFCs)

E. Innovation

10. Application of information and communications technology (ICT) to improve efficiency across the manufacturing and service sectors

3.1 CITIES

Shift to compact and connected urban growth

Total abatement potential in 2030: 1.5–3.3 Gt CO_2e

Abatement measures: Abatement potential in cities is estimated for:

- Shift to compact and connected urban growth (from shifts in transport and building energy demand): 0.6–1.9 Gt CO_2e
- Implementation of new and existing urban technologies which improve resource productivity: 0.7–1.4 Gt CO_2e

These components are in line with the substantive issues discussed in Chapter 2: Cities in the Commission's report.

Summary analysis

Research for the Commission identified emission reduction potential of more compact, transit-oriented cities of 0.6–1.9 Gt CO_2e per year by 2030 through more efficient land use and energy-efficient transport modes.[9] These estimates refer only to transport mode shifts and reduced building energy demand due to more efficient land use through higher-density development. (As discussed in the next section, there is also large complementary potential to reduce emissions through other mechanisms that improve building and transport energy efficiency.)

Assumptions and uncertainties

In a study for the Commission, Oxford Economics (OE) in partnership with London School of Economics (LSE) Cities, estimated baseline emissions from the world's largest 724 cities as 20 Gt CO_2e by 2030.[10] These cities cover two-thirds of world urban GDP and more than 60% of world urban population. City-level carbon emissions were derived from estimates of national-level emissions data from the International Energy Agency (IEA) and the US Energy Information Administration (EIA).[11] National-level estimates were combined with the city-level dataset to determine city-level emissions estimates for four sectors – manufacturing, transport, residential and other – using econometric modelling to forecast emissions to 2030.

The analysis estimated the emission reduction potential of more efficient land use and energy-efficient transport modes through a scenario with the following characteristics: (i) car ownership is reduced to the level of a leading benchmark city in each world region in 2030 (this changes the econometric estimates of transport emissions), and (ii) urban land area grows, at most, in proportion to population growth, consistent with more compact urban growth (this increases land use density and therefore the econometric estimates of residential emissions). The changes in car ownership are an indicator for a range of possible major adjustments cutting across all forms of new urban mobility (including shared mobility, a shift towards public transport, cycling and walking). Benchmark cities were identified based on having low car ownership levels, but above-average income levels.

This results in an abatement estimate of 1.4 Gt CO_2e in 2030. Additionally, the increase in land use density has potential to reduce residential emissions by reducing building energy demand, to the extent that urban dwellings are smaller or better insulated (multi-family dwellings have fewer exterior walls). Further research is required in this area, and given the uncertainty, we adopt a conservative value of 0.1 Gt CO_2e, for a total of 1.5 Gt CO_2e. Additional analysis by NCE staff to extend the estimates to include small urban areas indicates that another 0.2–0.4 Gt CO_2e per year of emission reductions by 2030 could be available.[12] This assumes that smaller urban areas could achieve 25–50% of the average per capita emission reductions that the largest 724 cities are projected to achieve. Given the large gap that currently exists between benchmark cities and the average, this scenario would entail rapid and far-reaching change.

As a complement to this top-down analysis, bottom-up analysis for the Commission by the Stockholm Environment Institute[13] uses IEA urban transport scenarios and data from the Global Buildings Performance Network on building energy demand. The analysis assumes a 20% reduction in building energy use resulting from smaller average residential and commercial units,[14] and a 40% potential emission reduction from expanded public transportation in 2050 relative to the reference case, based on results from the IEA's "avoid/shift" scenario.[15] The available savings from compact, transit-oriented cities on a global basis are estimated to be around 0.6 billion tonnes of CO_2e in 2030 (0.2 Gt CO_2e from buildings and 0.4 Gt CO_2e from transport). The difference in the estimates stems from different data and assumptions about the extent of transport modal shifts possible and different assumptions and estimation methods of the impact of more compact urban growth on emissions from the built environment.

Based on these different estimates, we adopt a range for emissions reductions estimates of 0.6–1.9 Gt CO_2e by 2030.

Costs and benefits

Chapter 2: Cities in the Commission's report provides an overview of the multiple economic benefits of more compact and connected urban growth. The evidence is highlighted in further detail in three NCE contributing papers. In summary, this analysis shows that by enabling greater density, the economic and social interactions associated with more compact urban growth create a vibrant market and fertile environment for innovation in ideas, technologies and processes, spurring innovation and productivity. More compact and connected patterns of urban growth significantly reduce the costs of providing services, infrastructure and transport, and generate multiple benefits related to reduced air pollution, congestion, improved public health and safety, and greater energy security.

When monetised, these benefits can add up to several percentage points of city GDP.[17] At the same time, there is no significant evidence to suggest more compact, connected urban development harms economic growth.[18] Some of the world's most competitive and liveable cities, including Hong Kong, Singapore, Copenhagen, Curitiba and Stockholm, have followed urban development pathways similar to those underlying the abatement scenarios described here with significant reductions in car ownership levels. An NCE contributing paper[19] provides a detailed analysis of the economic benefits and costs of shifting away from conventional vehicle travel and towards greater use of public transport and other low-carbon transport modes. This includes a survey of studies which quantify the positive impact on GDP and total employment from modal shifts away from conventional vehicle travel and the impact of increased investment in public transport relative to road-building.

Implementation of new and existing urban technologies

Summary analysis

Analysis produced by Siemens for NCE – using the company's City Performance Tool (CyPT)[20] – estimates the mitigation potential of the largest 812 cities in Asia, Europe, South America and North America, implementing 31 market-ready urban technologies in the transport, energy and building sectors in the period to 2025. These cities cover over two-thirds of world urban economic output and population. A full methodological note is available on request from Siemens via NCE. The analysis identifies abatement potential of 0.7–1.4 Gt CO_2e in 2030 through actions that meet the criteria for this analysis.

Assumptions and uncertainties

Siemens makes an assessment of what might be realistic implementation rates for the technologies analysed. The table below shows the assumptions by technology and region. This analysis suggests a total abatement potential of 2.4 Gt CO_2e per year by 2025.[21] To avoid double-counting with the emissions reductions estimated from a shift to a compact, connected urban growth scenario and from other analysis of the energy sector (see below) we subtract the abatement potential from all major transport technologies as well as that attributable to wind power and solar photovoltaics. We also considered several factors that could erode this emissions saving. First, rebound effects could lead to increased energy use and reduce the potential from energy efficiency improvements. Second, implementation rates could be constrained by a range of factors, including limited access to finance and other barriers as discussed in Chapter 2: Cities of the full NCE report. Third, although there is strong evidence that the energy efficiency measures included can be highly cost-effective, it is uncertain exactly what level of implementation would be cost-effective by 2030.

Given these uncertainties, we assume reduced implementation rates, so that cities reach the rates indicated in the table by 2030 rather than 2020. We also exclude urban areas with populations under 500,000, in recognition of the greater implementation challenges in such environments, including financing constraints and less favourable economies of scale. The resulting upper-bound estimate for the world's largest 812 cities is 1.4 Gt CO_2e in 2030. As a lower bound we halve the effective abatement potential to 0.7 Gt CO_2e in 2030, as a way of capturing possible greater rebound effects and reduced implementation.

These estimates relate only to a set of specific technologies in the specific cities. The global potential for cost-effective reductions of energy use in buildings has been estimated at much higher levels. For example, the *IPCC Fifth Assessment Report* notes that "final energy use may stay constant or even decline by midcentury, as compared to today's levels, if today's cost-effective best practices and technologies are broadly diffused", compared with a baseline two- to three-fold increase.[22] For context, total GHG emissions from buildings in 2010 were around 9 Gt CO_2e.[23]

Table 1: 31 market-ready urban technologies with implementation rates by region

Market-ready technology	Achieved by 20250	Europe	North America	South America	Asian
Wall insulation	Annual % annual implementation of total stock	1%	1%	2%	3%
Glazing	Annual % annual implementation of total stock	1%	1%	2%	3%
Commercial wall insulation	Annual % annual implementation of total stock	1%	1%	2%	3%
Commercial glazing	Annual % annual implementation of total stock	1%	1%	30%	40%
Metro - new line	Number of lines	1 line	0 line	2 lines	3 lines
Combine cycle gas turbine	% of energy mix	5%	3%	5%	5%
CHP	% of energy mix	5%	3%	5%	20%
Residential efficient lighting technology	Annual % annual implementation of total stock	2%	2%	2%	3%
Commercial efficient lighting technology	Annual % annual implementation of total stock	2%	2%	2%	3%
Demand oriented lighting	Annual % annual implementation of total stock	2%	2%	2%	3%
Building efficiency monitoring (BEM)	Annual % annual implementation of total stock	2%	2%	2%	3%
Building performance optimizaiton (BPO)	Annual % annual implementation of total stock	2%	2%	2%	3%
Demand controlled ventilation	Annual % annual implementation of total stock	2%	2%	2%	3%
Heat recovery	Annual % annual implementation of total stock	2%	2%	2%	3%
Automated train operation (ATO) metro	% of total metros	63%	30%	75%	70%
LED street lighting	% of total street lights	12%	32%	30%	45%
Electric cars	% of modal split	5%	3%	5%	10%

Market-ready technology	Achieved by 20250	Europe	North America	South America	Asian
Hybrid electric cars	% of modal split	6%	3%	5%	10%
Bike sharing	per 1,000 inhabitants	5	3	3	7
Wind	% of energy mix	14%	8%	4%	10%
PV	% of energy mix	12%	6%	5%	7%
Home energy monitoring	Annual % annual implementation of total stock	3%	3%	3%	4%
Home automation	Annual % annual implementation of total stock	3%	3%	3%	4%
Electric buses	% of buses	20%	10%	20%	30%
E-highways	% of highways changed to e-highway and trucks refitted	20%	10%	20%	20%
Intellilgent traffic light management	% of traffic lights	80%	70%	40%	60%
Plug-in hybrid electric cars	% of modal split	5%	3%	30%	10%
Electric taxis	% of taxis	5%	10%	5%	10%
Intelligent street lighting	% of lights	10%	5%	5%	50%
Electric car sharing	per 1,000 inhabitants	2	1	1	2
Intermodal traffic management	% of passengers using intermodal traffic information management systems	10%	12%	30%	60%

Note: Traditional technologies are shown in green. "Next generation" technologies are shown in yellow, and emerging technologies ("tech 3.0") in blue. Source: Siemens, 2014.[24]

Costs and benefits

As documented in Chapter 2: Cities of the Commission's report, there is evidence that applying new and existing urban technologies can have positive economic benefits. For example, the *IPCC Fifth Assessment Report* chapter on buildings reports that "the history of energy efficiency programmes in buildings shows that 25–30% efficiency improvements have been available at costs substantially lower than marginal supply", and that "the monetizable co-benefits of many energy efficiency measures alone often substantially exceed the energy cost savings".[25] As an additional example, a review of studies examining the economic case for investment in low-carbon development strategies across five cities internationally (Leeds, Kolkata, Lima, Johor Bahru and Palembang) finds numerous opportunities for cost-effective investments in developed and developing world cities covering many of the technologies outlined above.[26] A complementary study by Siemens for NCE showed the wider economic and environmental benefits of applying the technologies outlined in Table 1 across 30 of the world's "megacities". This study estimated that this could create over 2 million jobs, and achieve significant reductions in local air pollution by 2025. [27]

3.2 Land use

Total abatement potential in 2030: 4.2–10.4 Gt CO_2e

Abatement measures: Abatement potential for land use has four components:

- Boosting agricultural productivity: 0.6–1.1 Gt CO_2e
- Improved forest governance and conservation measures to achieve zero net deforestation: 1.6–4.4 Gt CO_2e
- Restoration of degraded landscapes – 150 million hectares of degraded agricultural land and 350 million hectares of degraded forests: 1.8–4.5 Gt CO_2e
- Reduced food waste: 0.2–0.4 Gt CO_2e

These components are in line with the issues covered in Chapter 3: Land Use in the Commission's report.

Boosting agricultural productivity

Summary analysis

There are several measures that improve agricultural productivity while also substantially reducing the intensity of the production of GHG emissions. We estimate the abatement in 2030 of adopting specific agricultural innovations at 0.6–1.1 Gt CO_2e per year, using three specific point estimates: (i) 0.3–0.7 Gt CO_2e per year in 2030 through more efficient use of water and fertiliser on crops other than rice; (ii) 0.15–0.25 Gt CO_2e per year in 2030 through better feeding and management of livestock; and (iii) 0.1–0.15 Gt CO_2e per year in 2030 from better water management of rice through improved varieties and practices. Increasing agricultural productivity can also reduce pressures to convert forests to cropland (further discussed in the deforestation section below).

Assumptions and uncertainties

Our baseline for agriculture-related emissions levels and composition is derived from the IPCC AR5 report and a study by Searchinger et al.[28] These show significant GHG emissions associated with the use of agricultural inputs. Several studies also show that both fertiliser and water are applied in excess of what is economically efficient. Specifically, one estimate for India suggests GHG emissions would be reduced by 0.3 Gt CO_2e per year in 2030 by reducing inputs to efficient levels,[29] and another study estimates an equivalent number for China of 0.1–0.3 Gt CO_2e per year.[30] We assume a further 0.1–0.3 Gt CO_2e would be available in other regions. The resulting global estimate thus is 0.7 Gt CO_2e per year from increasing economic efficiency in agricultural input use.

Work in progress at the Food and Agriculture Organization of the United Nations (FAO) finds that there is GHG abatement potential for livestock from improved feeding, pasture, and manure management that pays for itself in terms of sustained output growth.[31] The estimated potential is 0.15 Gt CO_2e from practices currently available, rising to 0.25 Gt CO_2e for practices that would require a credit valued at US$20 per tonne CO_2e of emissions reductions. We adopt these numbers as our low and high estimate for the potential contribution of livestock efficiency to abatement by 2030.

For efficiency in rice production, we base our estimates on intensification of rice cultivation in India.[32] Applying the rate of emissions savings in India to half the rice fields of Asia would result in emissions reductions of approximately 0.3 Gt CO_2e per year by 2030. However, the applicability of the relevant practices is yet to be established more widely; around 90% of rice is produced in Asia, mainly on small farms that face barriers to the adoption of the relevant measures. To account for this we use a lower range of 0.1–0.15 Gt CO_2e per year.[33]

Costs and benefits

The above measures have significant documented co-benefits, but they are difficult to quantify. By their nature, measures aimed at improving agricultural productivity are likely to increase farmer incomes and food production (and thus food security). One concrete channel for benefits is the potential to reduce subsidies for agricultural inputs. For example, eliminating 10–20% of irrigation and fertiliser subsidies in India and China would correspond to savings of US$3–6 billion (with full elimination resulting in up to US$30 billion of fiscal gains).[34]

Improved forest governance and conservation measures to achieve zero net deforestation in 2030

Summary analysis

We estimate the abatement potential from halting net deforestation at 1.6–4.4 Gt CO_2e per year in 2030. This is based on triangulating a range of estimates surveyed by the IPCC.[35]

Assumptions and uncertainties

There is significant uncertainty about the net GHG emissions from land use change. The IPCC recently surveyed 13 global process models assessing net emissions from all sectors for the period 2000–2009. It found the average estimate of emission reductions from halting deforestation as 4.4 Gt CO_2e, but with a substantial range of uncertainty of +/- 2.2 Gt. More recent estimates for the period 2002–2011 are lower (2.93 Gt CO_2e +/- 2.2 Gt) than those for 2000–2009.[36]

Another significant source of uncertainty is the extent to which lowered deforestation (land use change) implies lowered degradation (tree removal). It is possible to significantly increase tree removal, but have no impact on deforestation if the harvested areas are allowed to regenerate into forest instead of being converted to some other use. Higher degradation means greater immediate carbon loss, and the success in halting tree removal is thus a strong determinant of the extent to which emissions savings can be realised.

Our starting assumption is that baseline emissions remain relatively stable over time in the absence of additional policy action.[37] We adopt a central estimate of 3 Gt CO_2e net savings from halting deforestation and associated degradation, based on the IPCC mean estimate for 2002–2011.[38] For a high-end estimate we use the IPCC's meta-analysis average of 4.4 Gt CO_2e for 2000–2009, and adopt an equal proportionate lower-end estimate of 1.6 Gt CO_2e, to represent a case with lower baseline emissions, less success in halting deforestation, and/or less success in halting tree removal where deforestation is halted.

Costs and benefits

Halting deforestation could have substantial benefits through the ecosystem services provided by forests (assuming that stopping deforestation is matched for the most part by reduced tree harvest from natural forests). A major challenge is that these values are not internalised in actual markets in most cases, and are very challenging to value with confidence. Another uncertainty is that values can vary significantly with local conditions, and with changing scarcity. Global estimates nonetheless suggest that the values can be substantial. By one recent estimate, forests produced a net value of ecosystem services of approximately US$16 trillion, which on average would correspond to US$3,800 per ha per year in 2011, or US$3,100 per ha per year excluding the benefit of sequestering CO_2.[39] An expert panel at the United Nations Environment Programme (UNEP) estimated an equivalent value of US$6,120 per ha per year in 2014 for tropical forests, or US$4,000 per ha per year without CO_2 sequestration.[40] It is unclear how far these global average values would relate to the marginal change in ecosystem services resulting from different rates of deforestation. However, for illustration of the scale of potential benefit, applying the above per hectare values to the 5 million hectares that FAO estimated as deforested on a net basis each year in 2000–2009 gives a value of US$15–20 billion per year before accounting for climate benefits.[41]

Reducing deforestation also has costs – notably, the value of the forest products that could have been extracted, as well as any direct cost to implement reduced deforestation (e.g. REDD+ payments). The market value of timber and pulp varies by quality and location, and also changes over time depending on underlying demand growth and available supply (which in turn may be affected by reduced deforestation). This means that the marginal benefits of harvesting in particular locations may differ from global averages, and also may change significantly over time. For illustration, using current global market prices for forest products from the entire 5 million hectares typically deforested each year on a net basis gives an estimate of US$5–10 billion in sales revenue to deforesters.[42] If in addition US$5 billion per year of REDD+ payments were made, the combined expenditure and opportunity cost could be in the region of US$10–15 billion per year.

Adding GHG mitigation benefits would significantly add to the benefit side. For example, the Eliasch Review estimated the net benefits of halving deforestation by 2030, once the avoided damage costs of climate change are taken into consideration, at more than US$3.7 trillion over the long term.[43]

Restoration of degraded agricultural and forest landscapes

Summary analysis

We estimate the abatement potential from restoration of (i) degraded agricultural land (150 million hectares) at 0.5–1.7 Gt CO_2e per year, and (ii) degraded forest (350 million hectares) at 1.2–2.9 Gt CO_2e per year, providing a total range of 1.8–4.5 Gt CO_2e.

Assumptions and uncertainties

For agricultural (mainly soils) restoration, we assume the 150 million hectares are generated from 15 million hectares in intensive projects[44] and 135 million hectares of farmer-managed natural regeneration (FMNR) over 15 years to 2030. For the abatement potential from 15 million hectares in intensive projects, we base our estimates on the carbon savings achieved by two World Bank watershed rehabilitation projects in the Loess Plateau of China. These represent good practice in intensive landscape restoration projects implemented by multilateral financial institutions in concert with national governments. If the carbon savings achieved in this example were applicable to 15 million hectares, emissions would be reduced by 0.1 Gt CO_2e per year in 2030.[45]

For the 135 million hectares of FMNR we use the good practice example of 5 million hectares of agricultural landscape restoration in the Maradi-Zinder region of Niger, which achieved significant benefits at scale with minimal fiscal investment.[46] Independent estimates suggest carbon sequestration in this case of 2 tonnes of carbon per hectare per year (corresponding to 7.33 t CO_2e per ha per year), a common figure for drier tropical woody areas.[47] If this rate of sequestration were applicable to the full 135 million hectares, it would give a mean estimate of 1.0 Gt CO_2e per year in 2030.

The total illustrative estimate from intensive projects and FMNR therefore is 1.1 Gt CO2e. In consideration of the uncertainties around both sequestration rates (i.e. whether the Niger value is representative for a global portfolio of projects) and feasible implementation, we use a range around the mean of +/- 0.6 Gt, or 0.5–1.7 Gt CO_2e per year in 2030.

For forest restoration (mainly trees), we base our estimates on Verdone et al. (forthcoming), which estimates 1 Gt CO_2e sequestered from 150 million hectares of restoration. Applied to the area of 350 million hectares by 2030, this implies sequestration of 2.3 Gt CO_2e.[48] The study reported in Verdone et al. is based on an assumed mix of planted forest, naturally regenerated forests and agroforestry with different carbon sequestration potentials. For a lower end of the range, we assume the same mix would apply to the 350 million hectares, but that only half of the potential would actually be achievable. This results in a lower-end estimate of 1.2 Gt CO_2e per year in 2030. For the upper end of the range, we assume the full 350 million hectares are implemented, and the mix includes a greater proportion of agroforestry and other types of plantations with greater sequestration potential. We therefore adjust the number up by 25% from 2.3 Gt CO_2e to 2.9 Gt CO_2e per year to account for this possibility.

Costs and benefits

The evidence suggests that restoration of degraded agricultural land has significant economic benefits. FMNR can provide returns to farmers without substantial additional capital investment. For example, in Niger, after 20 years, real farm incomes had doubled on 900,000 farms (an addition of roughly US$1,000 per household in 2008 US dollars) or US$180 per hectare, soil fertility had improved enough to boost grain yields by 10% on average, and biodiversity had significantly improved.[49] The overall economic rate of return for the Loess Plateau projects was 21% when downstream and global benefits are included, and 18.5% without including them, generating US$800 per ha per year in income benefits.[50] Additionally, restoring degraded forests can include direct financial benefits from the sale of selectively harvested timber and non-timber forest products. In line with the discussion above, areas of restored forest that are not harvested also provide significant ecosystem services. As noted above, however, such valuations are uncertain and should be taken as illustrative of magnitudes rather than as precise estimates of benefits. Verdone et al. estimate a present value of US$84 billion for 150 million hectares of forest restoration. If the same average value applied to the 350 million hectares discussed here, the total value would be US$170 billion.

Reduced food waste

Summary analysis

We estimate the abatement potential from reducing food waste at 0.2–0.4 Gt CO_2e per year by 2030. This is based primarily on work for NCE by the Waste Resources Action Programme (WRAP).

Assumptions and uncertainties

WRAP has estimated that reducing global food loss and waste globally by 2030 could prevent 0.2–1.0 Gt in annual CO_2e emissions. Considerably more detailed analysis by WRAP for the United Kingdom found that 1.0 tonne of CO_2e emissions was saved per US$1,200 in food waste averted, measured in average 2007–2012 prices at the retail and household levels of the food chain.[52] Applying this UK conversion co-efficient globally would give a global estimate of 0.3 Gt. However, price levels, waste levels and consumption baskets vary considerably between different countries, which in turn result in variation in the value and extent of food waste that can be avoided. For comparison, the *IPCC Fifth Assessment Report* gives a range of 0.6–6.0 Gt in potential savings from food waste reduction by 2050.[53] Given the significant uncertainties about both country-level variation and feasible implementation, we adopt a range of 0.2–0.4 Gt as a more conservative estimate. This takes the lower end of the WRAP global estimate as its lower bound, and assumes double this amount as a higher-end estimate.

Costs and benefits

Reducing food waste can yield considerable financial savings. The FAO estimates potential global savings worth US$750 billion per year based on current total food loss and waste.[54] The UK has reduced its household food waste by 21% between 2007 and 2012 – even as the number of households increased by nearly 4%. This reduction saved food with a market value of roughly £3.3 billion (US$5.3 billion) in 2012 alone, and avoided 4.4 million tonnes CO_2e of emissions.[55] WRAP also estimated that a 20–50%

reduction in global consumer food waste in 2030, associated with the estimate of a 0.2–1.0 Gt reduction given above, could deliver savings of between 55 and 140 million tonnes of food per year (valued at around US$80–200 billion) based on 2011 waste levels, or 110–280 million tonnes of food (US$120–300 billion) on 2030 projected levels.

3.3 Energy

Total abatement potential in 2030: 4.6–6.6 Gt CO_2e

Abatement measures: Abatement potential for land use has four components:

1. Reduced coal use from efficiency and transition to lower-carbon fuels: 3.5–4.0 Gt CO_2e
2. Reduced methane emissions from the oil and gas sector: ~0.7 Gt CO_2e
3. Removal of fossil fuel subsidies: 0.4–1.8 Gt CO_2e

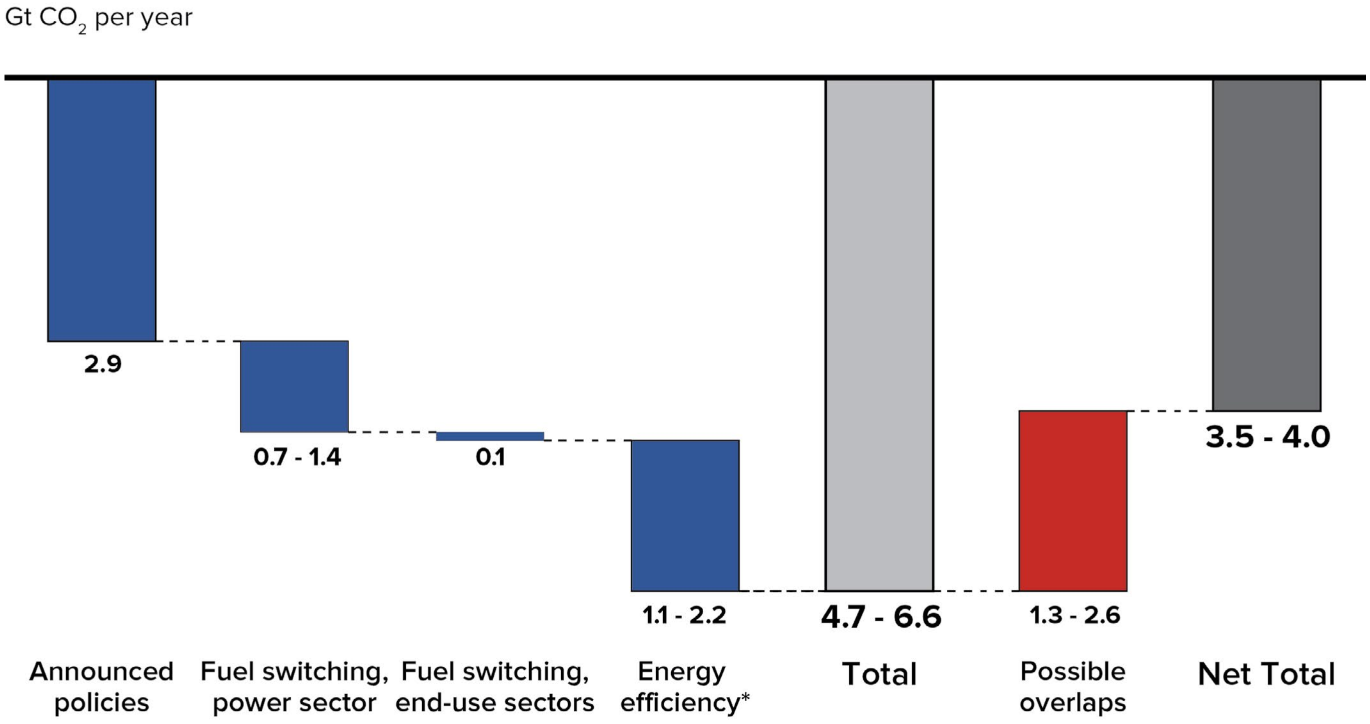
This is in line with Chapter 4: Energy of the Commission's report.

Reduced coal use from efficiency and transition to lower-carbon fuels

Summary analysis

We estimate the inital abatement potential from reducing the use of coal at 4.8–6.6 Gt CO_2e per year in 2030. Of this, 2.9 Gt CO_2e results from the adoption of policies already announced, spanning both energy efficiency and a switch from coal to other fuels. Another 0.7–1.4 Gt CO_2e results from switching from coal to other fuels, primarily through an increase of 750–1,500 TWh per year in low-carbon sources of power generation by 2030 that could be cost-effective when accounting for the falling costs of renewables compared with fossil fuels, and the benefits of lower air pollution. The remaining 1.1–2.2 Gt CO_2e results from reduced electricity and coal consumption in end-use sectors through increased energy efficiency, much of which is directly cost-effective in financial terms, but further strengthened by a range of other benefits. Of this total, 1.3–2.6 Gt CO_2e of abatement potentially overlaps with other measures in this document. Assuming 100% overlap gives a lower final abatement potential of 3.5–4.0 Gt CO_2e. Figure 3 summarises the composition of these estimates.

Figure 3: Cost-effective abatement potential by 2030 from reducing coal use



** Energy efficiency includes efficiency measures for electricity use, direct coal use in end-use sectors, and power plants.*

Assumptions and uncertainties

The scope of the analysis is limited to reduced coal use, following recommendation 10 in the Commission's Global Action Plan. We use the baseline for emissions developments in the "Current Policies" scenario in the IEA's *World Energy Outlook 2013*.[56] CO_2 emissions from coal combustion are 20 Gt in 2030 in this scenario, of which 15 Gt are from electricity generation.[57] IEA analysis suggests that policies already announced by national governments (the IEA "New Policies" scenario, or NPS) would result in an emissions reduction of 2.9 Gt CO_2e below this baseline. The potential to reduce emissions further is estimated from two main sources. We take the data underlying IEA's "450" scenario as a starting point for the maximum shift in electricity generation from coal to low-carbon sources that is feasible by 2030 without prematurely retiring generation assets.[58] This scenario sees an increase in zero-carbon sources of 3,700 TWh per year by 2030, in addition to the 1,300 TWh per year already adopted in the NPS scenario. After taking the falling cost of renewables, avoided costs of air pollution damages, and full costs and co-benefits of renewables into account, we make the assumption that 20–40%, or around 750–1,500 TWh, of this additional fuel switching beyond the levels in the NPS scenario can be cost-effective. As we discuss below, this is lower than the cost-effective potential outlined in the *REmap* analysis by the International Renewable Energy Agency (IRENA).[59] The associated emissions reductions, based on the emissions factors in different IEA scenarios, are 0.7–1.4 Gt CO_2e per year by 2030. We make similar assumptions for fuel switching away from direct coal use in end-use sectors, giving a further 0.1 Gt CO_2e per year of cost-effective abatement potential.

For energy efficiency, our starting point is the IEA "Efficient World" scenario.[60] This is based on an assessment of economically viable potential, as defined by the payback periods that would induce investors to commit funds to energy efficiency projects. This provides a baseline estimate of cost-effective potential on pure financial grounds. The reduction in coal use in the scenario beyond the NPS corresponds to approximately 2.9 Gt CO_2e by 2030.[61] For comparison, the 2013 "450" scenario contains energy efficiency savings through reduced coal use of 2.8 Gt CO_2e.[62] We use this technical potential as a starting point but adjust for a number of uncertainties. First, it is uncertain to what extent the implementation of these measures would result in an increase in energy use, as consumers respond to higher efficiency by increasing their consumption ("rebound").[63] Such rebound effects would eliminate some emissions savings, absent other policy intervention. An additional source of uncertainty is the feasible rate of improvement in energy efficiency. Finally, the full cost-effectiveness of energy efficiency measures is sometimes disputed, although there are factors that could both detract from and further improve cost-effectiveness beyond the financial assessment that underlies the estimates used here (see below). Consideration of these factors causes us to reduce the potential to 1.1 Gt CO_2e (40%) as a lower bound, and 2.2 Gt CO_2e (80%) as an upper bound. The total estimated potential thus is 4.8–6.6 Gt CO_2e. To avoid any possible double-counting, we subtract all possible coal-related abatement in the energy efficiency measures in the Cities section (0.3–0.6 Gt) and Manufacturing and Services sections below (0.6–1.2 Gt), as well as from removal of fossil fuel subsidies below (0.5–0.9 Gt). This amounts to an assumption that these measures overlap 100% with the efficiency and fuel-switching measures described here. In reality, the degree of overlap is likely to be smaller, which would result in a higher abatement potential.

Costs and benefits

There is significant uncertainty about the feasible pace and cost-effectiveness of future deployment of alternatives of coal-fired power. The IRENA *REmap* 2030 options indicate significant potential to use renewable energy sources at no or small net cost (in terms of the levelised cost of energy) by 2030.[64] The electricity generation potential estimated to be cost-effective by 2030 corresponds to as much as 40–60% of the total potential identified by IRENA or around 1,800–3,200 TWh more than in the IEA NPS.[65] This is substantially more than the 750–1,500 TWh assumed to be cost-effective in our analysis. We nonetheless take a more conservative approach to reflect a number of factors (see the main NCE report for more detail). First, the *REmap* options describe potential in 2030, but much of the relevant capacity needs to be put in place at earlier dates, when the relative economics of electricity from RES is likely to be less favourable. Second, there is significant divergence in estimates of future cost-effective potential; while the *REmap* 2030 is based on detailed bottom-up assessments of national renewable energy potential, other analyses (such as those by the IEA as well as the US EIA, for example), suggest the cost-effective potential could be smaller. The divergences reflect differences in views about highly uncertain parameters including future cost developments in renewable energy technologies and fossil fuel prices. Third, the appropriate valuation of the health impacts of air pollution is uncertain. The large range in the IRENA numbers reflects this, but analysis carried out for the Commission[66] suggests that reducing air pollution might in fact be even more valuable than indicated in the IRENA analysis, which would give a still higher cost-effective potential. On the other hand, the monetisation of such damages is highly uncertain, especially in developing countries. Fourth, the use of renewable energy at scale adds costs that are not reflected in bottom-up modelling, as discussed in the main NCE report. These include system integration costs, but also potential negative knock-on impacts associated with the use of renewable energy sources, including hydropower and bioenergy. These can limit the feasible rate of expansion as well as erode the extent of total potential that is truly cost-effective from a social perspective. Our final assumption for the cost-effective potential therefore is only around 40–50% of that indicated by *REmap* options analysis, and corresponds to 20–40% of the total potential beyond the NPS scenario that is consistent with avoiding significant additional costs through premature stranding of pre-existing capital assets. For energy efficiency, we start from potential that is estimated to be cost-effective, as noted above. Several other factors are also relevant in determining the ultimate cost-effectiveness of improving energy efficiency. First, macroeconomic knock-on effects of improved energy efficiency can lead to an increase in GDP, as modelled by the Organisation for Economic Co-operation and Development (OECD) on the basis of the IEA's "Efficient World" scenario. Second, improved energy efficiency has multiple other benefits, including reduced pollution, enhanced energy security, improved health and well-being, and improved fiscal performance.[67] Third, as a counteracting factor, there is some uncertainty about whether untapped energy efficiency potential not only reflects market failures, but also has "hidden and missing" costs that are not represented in engineering-economic modelling, ranging from opportunity cost of scarce capital or management attention, to reduced performance on various dimensions valued by consumers.[68] Fourth, the implementation of policy to overcome barriers to energy efficiency can require market interventions that in turn have other consequences: positive effects can include more rapid innovation and thus further reduction in the future cost of reducing energy use, while negative market impacts can include more restricted choice for consumers with negative welfare impacts. These factors can have a significant cumulative impact on the value of energy efficiency initiatives. For example, as noted in the discussion of building energy efficiency measures in Section 4.1, the IPCC review of the literature concludes that the value of monetised co-benefits can be even larger than the value of energy savings. However, to reflect the possibility that the balance of factors may be negative (along with the rebound and implementation issues noted above) we take a lower bound estimate of 40% of the potential estimated in the "Efficient World" scenario, while the upper bound estimate of 80% corresponds to a more optimistic view or higher value placed on co-benefits.

Reduced methane emissions from the oil and gas sector

Summary analysis

We estimate the net zero-cost abatement potential for reducing methane emissions in the oil and gas sectors at 0.7 Gt CO_2e per year in 2030. This is based on analysis by the US Environmental Protection Agency (EPA), which provides estimates of the cost-effective share which can be used – as with coal – to indicate feasible implementation potential.

Assumptions and uncertainties

The EPA estimates that 1.2 Gt CO_2e per year can be abated globally by 2030, based on evaluating a series of technical abatement measures such as directed inspection and maintenance, installing plunger lift systems in gas wells, and reducing emission completions for hydraulically fractured natural gas wells. They also estimate that 0.7 Gt CO_2e of this is achievable at no net cost.[69] We use this as the basis of our estimate. There are numerous uncertainties attached to this number. For a start, the extent of methane leakage is poorly understood, and several studies suggest that it might be higher than previously thought.[70] Both baseline numbers and abatement potential therefore might be understated. In addition, the EPA estimates use a global warming potential (GWP) for methane of 21, which is low by current standards. Using the 100-year GWP of 34 adopted by the IPCC's *Fifth Assessment Report* would yield a substantially higher potential of 1.1 Gt CO_2e. Finally, there is some overlap with other measures described in this note, of which reduced oil consumption through transport energy efficiency and reduced energy subsidies (see next section) are likely the most significant. We have not attempted to translate these overlaps into an adjusted abatement potential, as the relationship between marginal changes to the level of oil consumption and upstream methane emissions is far from established. While several of these factors (and especially the GWP number) could lead to an increased potential, we take a cautious approach and adopt the EPA estimate of 0.7 Gt CO_2e directly. This also builds in some margin to account for obstacles to achieving the full rate of global implementation underlying the number.

Costs and benefits

As above, analysis by the EPA suggests a large share of abatement from reducing methane emissions in the oil and gas sectors can be achieved at zero or negative cost, without including any co-benefits other than the value of the recovered gas. The value of this gas depends on the price of natural gas, and a higher or lower price thus could lead to higher or lower estimates of the cost-effective potential. In addition, as discussed in an NCE background paper, methane has adverse environmental impacts, including as a precursor to the formation of ozone that, in turn, damages crop yields and human health.[71] This further supports the case for cost-effective abatement, although we have not estimated the potential size of this benefit.

Removal of fossil fuel subsidies

Summary analysis

We estimate the abatement potential from removing fossil fuel subsidies as 0.4–1.8 Gt CO_2e per year in 2030, once adjusted for potential overlap and interaction with other measures. This includes subsidies for the production and direct consumption of oil, gas and coal, as well as indirect consumption through electricity subsidies. The limits of the range are based on the IEA's "4-for-2" scenario, and on the *World Energy Outlook 2011*, respectively.

Assumptions and uncertainties

The IEA estimates in a 2013 analysis that CO_2 emissions from fossil fuels can be reduced by 0.4 Gt in 2020 by reducing fossil fuel consumption subsidies.[72] The underlying assumptions include a total phase-out by 2020 in importing countries, but a more gradual phase-out in exporting countries. We use this estimate for 2020 as the lower end of our range for 2030, corresponding to a much slower pace of subsidy reform. For an upper range estimate, we use IEA's analysis from the *World Energy Outlook 2011*, which calculates the implications of a complete phase-out of fossil fuel consumption subsidies in a selection of countries that currently have large subsidy levels, including subsidies for use of fossil-generated electricity.[73] This would result in a 2.3 Gt reduction in CO_2 emissions by 2030;[74] 0.5 Gt of this results from reduced oil use. As this potentially overlaps with reduced transport-related emissions in cities, we subtract this amount (assuming a 100% overlap). The final estimate for the top end of our range is thus 1.8 Gt of abatement potential in 2030.

Costs and benefits

Subsidies introduce significant economic inefficiencies, as documented in the main NCE report, which outlines why their removal would be consistent with promoting higher-quality growth. Energy subsidies can aggravate budget deficits and therefore reduce state capacity, and in energy-importing countries also exert pressure on the balance of payments. They can also depress growth by depressing investment in the energy sector, crowding out public spending that otherwise would promote growth, and distorting the structure of the economy towards lower-value energy-intensive sectors. By pushing up energy consumption, subsidies also increase negative health and other external effects of energy consumption. Finally, in many cases, subsidies can widen the gap between rich and poor, compared with more targeted welfare mechanisms. Although the negative effects of such subsidies are substantial, their removal can also result in negative impacts for vulnerable people. As also noted in the main NCE report, the removal of subsidies therefore would need to be accompanied by complementary measures to address equity and distributional concerns.

3.4 Short-lived climate pollutants: phasing out HFCs

Total abatement potential in 2030: 0.5–2.1 Gt CO_2e

Abatement measures: Reducing HFCs through regulation

This is in line with recommendation 2 in the NCE Global Action Plan that includes the phase-out of hydrofluorocarbons.

Summary analysis

We use a range of existing estimates that identify a likely range of abatement potential in 2030 from phasing out HFCs of 0.5–2.1 Gt CO_2e.[75] The wide range represents uncertainty both about the abatement potential, and about the share of reductions that would be cost-effective.

Assumptions and uncertainties

The three main categories of short-lived climate pollutants are black carbon, methane, tropospheric ozone and hydrofluorocarbons (HFCs).[76] We have accounted for methane from oil and gas emissions in section 3.3 above, and in addition to this consider HFCs in this section.

Existing estimates of HFC emissions diverge both in their assumed baseline emissions and estimated abatement potential. Analysis by Velders et al. (2009) estimates that under a base case in 2050, global emissions of HFCs would be 5.5–8.8 Gt CO_2e/year,[77] and 2.5–4 Gt in 2030. In contrast, the OECD's baseline for HFCs, as well as other f-gases – perfluorocarbons (PFCs) and sulphur hexafluoride (SF6) – is 1.8 Gt in total in 2030. A third source is the US EPA, which projects that the global HFC emissions will increase more than four-fold between 2010 and 2030, reaching 1.9 Gt CO_2e per year in 2030.[78] A study by ClimateWorks and the European Climate Foundation[79] suggests that f-gases – a significant proportion of which are HFCs – are likely to amount to 1.6 Gt in 2030, with a significantly lower estimate of 0.6 Gt in feasible abatement potential. Deducting non-HFC related gases brings this to ~0.5 Gt in 2030.

To determine the upper end of our range we assume HFCs are reduced by 85–90% by 2030, as would occur under the American and Micronesian proposals made in 2014 for phasing out HFCs under the Montreal Protocol.[80] We use the lower end of the Velders range, which provides an estimate of ~2.1 Gt CO_2e/year in 2030 if actions to amend the Montreal Protocol are fully implemented. However, Velders should be considered an upper-end estimate, as it assumes higher growth rates in major HFC-consuming sectors than other studies, particularly a large growth in refrigeration and air conditioning in developing countries. It also assumes developing countries use the same mix of HFCs (to replace ozone-depleting substances) as is done by developed countries. For a lower-end estimate we therefore adopt the values from ClimateWorks and the European Climate Foundation, of around 0.5 Gt in 2030.

Costs and benefits

Low-cost alternatives exist for HFCs in all major sectors, albeit not in all applications. A UNEP-TEAP assessment found that many alternatives achieve at least equal – and sometimes up to 30% greater – energy efficiency.[81] Similarly, a 2011 study for the European Commission also indicated that technically feasible and cost-effective alternatives exist. This analysis, which was prepared in association with industry, research institutes and other technical experts, analysed HFC alternatives available in 26 subsectors; all alternatives identified achieved at least equal energy efficiency and more often resulted in energy savings compared with commercially available HFC-based equipment.[82] The efficiency gains from moving away from HFCs to more energy-efficient alternatives could lower the cost of operating equipment and save consumers and governments money.[83] Overall, the cost of actions to reduce HFCs has been estimated at less than a dollar per tonne of CO_2e, although there is considerable uncertainty about how costs might vary when moving towards the upper end of the likely range of abatement potential.[84] A more detailed summary of the evidence – including the efficiency gains from phasing down HFCs, the growing support from leading businesses across developed and developing countries, and national and regional policy support – is outlined in a recent primer on HFCs by the Institute for Governance & Sustainable Development (IGSD).[85] Overall, the uncertainty in the extent of cost-effective potential is another reason that we adopt a wide range for the 2030 abatement estimates.

3.5 Manufacturing and service innovations

Total abatement potential in 2030: ~2 Gt CO_2e

Abatement measures: Application of information and communications technology (ICT) to improve efficiency across the manufacturing and service sectors

This links to Chapter 4: Energy and Chapter 7: Innovation of the Commission's report.

Summary analysis

We draw on the Global e-Sustainability Initiative's *SMARTer* 2020 report to derive estimates of abatement potential from the application of information and communications technology (ICT) to improve efficiency across the manufacturing and service sectors. The estimated abatement potential is 2 Gt CO_2e by 2030.

Assumptions and uncertainties

The SMARTer 2020 report is one of the few available estimates of the abatement potential associated with the application of ICT and is based on analysis by the Boston Consulting Group. The study estimates the abatement potential of ICT as 9.1 Gt in 2020 across six sectors: power (2 Gt), transport (1.9 Gt), buildings (1.6 Gt), agriculture (1.6 Gt), manufacturing (1.3 Gt) and services (0.7 Gt).[86]

To avoid double-counting with other categories of abatement estimates in this overall analysis, we use only the abatement potential estimates from the application of ICT in the manufacturing and service sectors, which add up to 2 Gt CO_2e in 2020. Of these, the two measures with the largest potential are in the manufacturing sector. The automation of industrial processes could yield an estimated 15% reduction in energy use. This excludes energy used for industrial cooling and heating, in which there is little opportunity for automation. The report estimates that the adoption by 33% of relevant manufacturing facilities would result in an abatement potential of 0.72 Gt CO_2e out of total relevant emissions of 14.3 Gt CO_2e. The optimisation of variable-speed motor systems could yield an estimated 30% increase in energy efficiency. With 60% adoption, the abatement potential through reduced electricity requirements would amount to 0.53 Gt CO_2e out of a total of 2.92 Gt CO_2e. Consultation with experts suggests that these potential savings are technically available, but that implementation rates may be overly optimistic given historic rates of adoption. We therefore assume that, with policy support, the absolute extent of adoption examined for 2020 is achievable but would require another decade beyond 2020, which gives the 2030 potential noted above.

Costs and benefits

A range of studies look at the potential for energy savings from improving energy efficiency through the application of ICT across the manufacturing and services sectors. For example, a study from the US by the American Council for an Energy-Efficient Economy (ACEEE), looking at the energy savings potential from applications in manufacturing, concluded that the manufacturing sector could realise savings of US$15 billion in annual electricity costs by 2035.[87] Experts in the field of manufacturing automation expect that, on average, companies will realise a 20% reduction in energy intensity through the application of such technologies. These results are corroborated by other recent studies, such as one by the World Wildlife Fund (WWF) and the Carbon Disclosure Project (CDP) looking at the US corporate sector, which demonstrates the considerable savings that can be generated by upgrading technologies in manufacturing and services, including motor systems.[88] The economic potential of abatement enabled by such technologies is outlined in further detail in Chapter 7: Innovation of the NCE report – including digitisation and dematerialisation, as well as simulation, automation, redesign or control to optimise a process, activity, function or service.

4. ACKNOWLEDGMENTS

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ENDNOTES

[1] See Figure SPM.4 in: *IPCC, 2014. Summary for Policymakers. In Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, et al. (eds.). Cambridge University Press, Cambridge, UK, and New York. Available at: http://www.mitigation2014.org.

[2] See Table SPM.1 in IPCC, 2014. Summary for Policymakers, cited above.

[3] All emissions baselines are subject to a significant degrees of uncertainty, mainly due to uncertainty in GDP growth and population growth assumptions as well as uncertainty around the carbon-intensity of development paths countries choose. Baseline scenarios for 2030 compatible with > 1000 parts per million (ppm) CO_2e by 2100 range from 61 Gt CO_2e (10th percentile) to 73 Gt CO_2e (90th percentile). Emissions levels consistent with 430–480 ppm CO_2e, which provide scenarios in which it is likely that the temperature rise can be kept to less than 2°C by 2100, range from 28 Gt CO_2e (10th percentile) to 52 Gt CO_2e (90th percentile). This provides an emissions reduction target in the range of 21–33 Gt CO_2e if we compare the 10th and 90th percentiles of the baseline and emissions trajectory consistent with 2°C.

[4] Specifically, the figure shows: scenarios associated with a <33% probability that warming by 2100 relative to 1850–1900 will be less than 3°C; a <50% probability that it will exceed 4°C; and scenarios associated with a >66% probability of keeping warming under 2°C.

[5] As the figure shows there is a wide span both of possible developments in the next 15 years and in what is required and feasible thereafter. There are many combinations of baseline developments as well as post-2030 mitigation scenario developments where greater reductions by 2030 would be required to make a longer-term 2˚C target feasible. The post-2030 uncertainty is beyond the scope of issues considered here but adds to the reasons that estimates of what is required to bridge the gap between the baseline and a pathway consistent with the 2°C target are highly uncertain. This also is one of the reasons that we present a wide range in the estimates in this note. See, for example: Riahi, K., Dentener, F., Gielen, D., Grubler, A., Jewell, J., et al., 2012. Chapter 17: Energy pathways for sustainable development. In *Global Energy Assessment: Toward a Sustainable Future*. Cambridge University Press, Cambridge, UK, and New York, and International Institute for Applied Systems Analysis, Laxenburg, Austria. 1203–1306. Available at: http://www.globalenergyassessment.org.

[6] See endnote 1.

[7] Riahi et al., 2012. Chapter 17: Energy pathways for sustainable development, cited above. See also: 2DS Scenario from: International Energy Agency (IEA), 2014. *Energy Technology Perspectives 2014*. Paris. Available at: http://www.iea.org/etp/etp2014/.

[8] Clarke, L. and Jiang, K., 2014. Chapter 6: Assessing Transformation Pathways. In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, et al. (eds.). Cambridge University Press, Cambridge, UK, and New York. Available at: http://www.mitigation2014.org.

[9] See Floater, G., Rode, P., Robert, A., Kennedy, C., Hoornweg, D., Slavcheva, R. and Godfrey, N., 2014. *Cities and the New Climate Economy: The Transformative Role of Global Urban Growth*. New Climate Economy contributing paper. LSE Cities, London School of Economics and Political Science. To be available at: http://newclimateeconomy.report and Erickson, P. and Lee, C. M., 2014. *What Impact Can Local Economic Development in Cities Have on Global GHG Emissions? Assessing the Evidence*. New Climate Economy contributing paper. Stockholm Environment Institute, Seattle, WA, US. Available at: http://newclimateeconomy.report.

[10] For further details on the variables and data used, see: Floater, G., Rode, P., Robert, A., Kennedy, C., Hoornweg, D., Slavcheva, R. and Godfrey, N., 2014. *Cities and the New Climate Economy: The Transformative Role of Global Urban Growth*. New Climate Economy contributing paper. LSE Cities, London School of Economics and Political Science. Available at: http://newclimateeconomy.report.

[11] Energy forecasts were taken from the Oxford Economics Global Macroeconomic Model. Oxford Economics' energy forecasts reflect demand for energy by industry, transport, electrical power and cooking. As standard they take into account the IEA's "new policy scenario" forecasts, which assume existing policies plus the anticipated impact of the cautious implementation of declared policy changes. For the purposes of this project, these forecasts were adjusted to reflect the IEA's "no new policies scenario".

[12] The additional areas include 26 cities in the Oxford Economics Global 750 Cities dataset with populations under 500,000 people, as well as other areas not included in the 724 cities in the original analysis but classified as "urban" in: United Nations, 2014. *World Urbanization Prospects: The 2014 Revision*. Department of Economic and Social Affairs, Population Division, New York. Available at: http://esa.un.org/unpd/wup/.

[13] Erickson, P. and Lee, C. M., 2014. *What Impact Can Local Economic Development in Cities Have on Global GHG Emissions? Assessing the Evidence*. New Climate Economy contributing paper. Stockholm Environment Institute, Seattle, WA, US. Available at: http://newclimateeconomy.report.

[14] This is roughly consistent with the reduced floor area scenarios in the GBPN study: Ürge-Vorsatz, D., Petrichenko, K., Antal, M., Staniec, M., Ozden, E. and Labzina, E., 2012. *Best Practice Policies for Low Carbon & Energy Buildings: A Scenario Analysis*. Research report prepared by the Center for Climate Change and Sustainable Energy Policy (3CSEP) for the Global Buildings Performance Network. Paris. Available at: http://

www.gbpn.org/reports/best-practice-policies-low-carbon-energy-buildings-based-scenario-analysis. It is slightly higher than the 10% energy savings potential found in a comparative study of low- and high-density residential structures around Phoenix, Arizona, in the US: Chester, M. V., Nahlik, M. J., Fraser, A. M., Kimball, M. A. and Garikapati, V. M., 2013. Integrating Life-Cycle Environmental and Economic Assessment with Transportation and Land Use Planning. *Environmental Science & Technology*, 47(21). 12020–12028. DOI:10.1021/es402985g.

[15] See: International Energy Agency (IEA), 2012. *Energy Technology Perspectives 2012: Pathways to a Clean Energy System*. Paris. Available at: http://www.iea.org/etp/publications/etp2012/. The SEI analysis only estimates reductions in CO_2 emissions due to avoided trips and shifts to public transport with regard to passenger travel.

[16] Floater, G., Rode, P., Robert, A., Kennedy, C., Hoornweg, D., Slavcheva, R. and Godfrey, N., 2014. *Cities and the New Climate Economy: the transformative role of global urban growth*. New Climate Economy contributing paper. LSE Cities, London School of Economics and Political Science. Available at: http://newclimateeconomy.report.

Floater, G., Rode, P., Friedel, B. and Robert, A., 2014. *Steering Urban Growth: Governance, Policy and Finance*. New Climate Economy contributing paper. LSE Cities, London School of Economics and Political Science. Available at: http://newclimateeconomy.report.

Rode, P., Floater, G. and Thomopoulos, N., 2014. *Accessibility in Cities: Transport and Urban Form*. New Climate Economy contributing paper. LSE Cities, London School of Economics and Political Science. Available at: http://newclimateeconomy.report.

[17] See: Rode et al., 2014, *Accessibility in Cities: Transport and Urban Form*, for further detail.

[18] Set against this is the potential impacts of modal shifts away from private vehicle use on automobile manufacturing. Unfortunately, comparative studies of the employment intensity and domestic value addition of different modes of transport are frequently unavailable, and the contribution of the automobile sector to value added and employment varies widely between countries. Despite the status of the automobile industry in some economies, some studies have shown significant positive net macroeconomic effects from reducing car use across a range of different policy packages. Moreover, in comparative terms, several studies have confirmed the economic benefits of increased investment in public transport modes relative to private motor vehicles. See Rode et al., 2014, *Accessibility in Cities: Transport and Urban Form*, for further detail.

[19] Rode et al., 2014. *Accessibility in Cities: Transport and Urban Form*.

[20] Siemens, 2014. *Urban Infrastructure in 2025, The Economic Impacts of Implementing Green Technologies in the World's Megacities*. Addendum 11/07/2014. New Climate Economy call for evidence submission. Available on request. The tool relies on proprietary Siemens data on the environmental performance of actual technologies currently being implemented in cities across the world.

[21] The baseline was determined by estimating per capita annual CO_2e emissions for 2014 and 2025 for four regional city types based on energy, transport and floor space demand and regional transport modalities and energy mixes, and using city-level population data to determine the 2014 and 2025 CO_2 baselines.

[22] Lucon, O. and Ürge-Vorsatz, D., 2014. Chapter 9: Buildings. In *Climate Change 2014: Mitigation of Climate Change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, et al. (eds.). Cambridge University Press, Cambridge, UK, and New York, p4. Available at: http://www.mitigation2014.org.

[23] Lucon, O. and Ürge-Vorsatz, D., 2014, p8.

[24] Siemens, 2014.

[25] Lucon, O. and Ürge-Vorsatz, D., 2014. Chapter 9: Buildings. In *Climate Change 2014: Mitigation of Climate Change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, et al. (eds.). Cambridge University Press, Cambridge, UK, and New York. Available at: http://www.mitigation2014.org.

[26] Gouldson, A., Colenbrander, S., McAnulla, F., Sudmant, A., Kerr, N., Sakai, P., Hall, S. and Kuylenstierna, J. C. I., 2014. *Exploring the Economic Case for Low-Carbon Cities*. New Climate Economy contributing paper. Sustainability Research Institute, University of Leeds, and Stockholm Environment Institute, York, UK. Available at: http://newclimateeconomy.report.

[27] Siemens, 2014. *Urban Infrastructure in 2025, The Economic Impacts of Implementing Green Technologies in the World's Megacities*. New Climate Economy call for evidence submission. The analysis suggests over 28 million FTE jobs could be created corresponding to a standard working year of 1,760 hours spent by one or more workers in installation, operations or maintenance activities. This is equivalent to over 2 million permanent jobs over the period of analysis (2014–2025). See jobs discussion in Chapter 5: Economics of Change of the Commission's report.

[28] See: Searchinger, T., Hanson, C., Ranganathan, J., Lipinski, B., Waite, R., Winterbottom, R., Dinshaw, A. and Heimlich, R., 2013. *Creating a Sustainable Food Future: A Menu of Solutions to Sustainably Feed More than 9 Billion People by 2050*. World Resources Report 2013–14: Interim Findings. World Resources Institute, the World Bank, United Nations Environment Programme (UNEP), United Nations Development Programme (UNDP), Washington, DC. Available at: http://www.wri.org/publication/creating-sustainable-food-future-interim-findings.

Smith, P. and Bustamante, M., 2014. Chapter 11: Agriculture, Forestry and Other Land Use (AFOLU). In *Climate Change 2014: Mitigation of Climate Change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, et al. (eds.). Cambridge University Press, Cambridge, UK, and New York. Available at: http://www.mitigation2014.org.

The IPCC reports net total anthropogenic GHG emissions from agriculture, forestry and other land use (AFOLU) in 2010 as 10–12 Gt CO_2e, or 24% of all GHG emissions in 2010; it further specifies that GHG emissions from agriculture in 2000–2009 were 5.0–5.8 Gt CO_2e per year.

[29] Hoda, A., 2014. *Low Carbon Strategies for India in Agriculture and Forestry*. Unpublished paper presented at The Indian Council for Research on International Economic Relations (ICRIER) Workshop on the New Climate Economy, ICRIER, India Habitat Center, New Delhi, 15 April.

[30] Zhang, W., Dou, Z., He, P., Ju, X.-T., Powlson, D. et al., 2013. New technologies reduce greenhouse gas emissions from nitrogenous fertilizer in China. *Proceedings of the National Academy of Sciences*, 110(21). 8375–8380. DOI:10.1073/pnas.1210447110.

[31] Gerber, P. J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. and Tempio, G., 2013. *Tackling Climate Change through Livestock: A Global Assessment of Emissions and Mitigation Opportunities*. Food and Agriculture Organization of the United Nations, Rome. Available at: http://www.fao.org/docrep/018/i3437e/i3437e.pdf.

Shindell, D., Kuylenstierna, J. C. I., Vignati, E., van Dingenen, R., Amann, M. et al., 2012. Simultaneously mitigating near-term climate change and improving human health and food security. *Science*, 335(6065). 183–189. DOI:10.1126/science.1210026.

Supplemented by personal communication from Dr. P. Gerber. The arguments here are laid out in more detail in Chapter 3: Land Use in the NCE report.

[32] Specifically, the estimates refer to an alternate wetting-and-drying approach typical of but not limited to the so-called System of Rice Intensification or SRI. See: Jain, N., Dubey, R., Dubey, D. S., Singh, J., Khanna, M., Pathak, H. and Bhatia, A., 2014. *Mitigation of greenhouse gas emission with system of rice intensification in the Indo-Gangetic Plains*. Paddy and Water Environment, 12(3). 355–363. DOI:10.1007/s10333-013-0390-2.

[33] For comparison, note that the IPCC estimates a range of 170–210 Mt CO_2e with a US$20–50/t CO_2e carbon price to capture the likely levels of financial support that might be required to unlock mitigation levels.

[34] The amounts and rationale for using these two largest of countries for raising the issue are given in Chapter 3: Land Use in the main report. The inefficient use of inputs due to subsidies is not limited to Asia by any means..

[35] These are summarised in Clarke, L. and Jiang K., 2014. Chapter 6: Assessing Transformation Pathways. In *Climate Change 2014: Mitigation of Climate Change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, et al. (eds.). Cambridge University Press, Cambridge, UK, and New York. Available at: http://www.mitigation2014.org.

[36] See Table 6.2 in: Clarke, L. and Jiang, K., 2014. Chapter 6: Assessing Transformation Pathways.

[37] Some studies assume LULUCF emissions may decline between 2010 and 2030 (for example, OECD's *World Environmental Outlook, 2012*). However, other bottom-up estimates – such as that undertaken by McKinsey (forthcoming) for a new Global Abatement Cost Curve – suggest emissions from forestry will still account for 7 Gt in 2030, remaining static over time. Moreover, a declining baseline is not consistent with the latest evidence on the trends in global gross tree cover loss from remote sensing (see www.GFW.org, for example). There is also a lot of uncertainty about the projected trends, but the main global drivers of forest degradation remain significant (e.g. timber and pulp demand in the BRICS countries and charcoal in Africa).

See also: McKinsey, 2014 (forthcoming). *McKinsey's Global GHG Abatement Cost Curve v.3.0*. Available at: http://www.mckinsey.com/client_service/sustainability/latest_thinking/greenhouse_gas_abatement_cost_curves; and Kissinger, G., Herold, M. and de Sy, V., 2012. *Drivers of Deforestation and Forest Degradation: A Synthesis Report for REDD+ Policymakers*. Lexeme Consulting, Vancouver. Available at: https://www.gov.uk/government/publications/deforestation-and-forest-degradation-drivers-synthesis-report-for-redd-policymakers.

[38] For example, according to the FAO, net deforestation amounts to 5.2 M ha/year, based on the average of the preceding 10 years. Halting net deforestation could imply that an additional area equivalent to 5.2 million hectares is allowed to regenerate into forest, rather than being converted after tree removal into another land use. Alternatively it could imply the regeneration of forest on 5.2 million hectares that was previously cut down and shifted into another land use (i.e. no forest degradation and no land use change). The actual carbon savings involved depend on whether any of the halted deforestation also involved halting the associated forest degradation, such that trees were not cut down in the first place. If the annual 5.2 million hectares were all harvested but allowed to regenerate, net deforestation would be halted, but the 5.2 million hectares would conservatively sequester only 0.038 Gt of CO_2e/year while regenerating. If the 5.2 million hectares were instead left intact (without tree removal), this would imply an emissions savings of up to 5.1 Gt of CO_2e relative to complete tree harvest with no regeneration and a significant fall in wood products production (see: Houghton, 2013, The emissions of carbon from deforestation and degradation in the tropics: Past trends and future potential, *Carbon Management*, 4(5), 539–546). The 3 Gt CO_2e estimate thus can also be interpreted as assuming that 60% of the trees on the land saved from deforestation are not cut down – in addition to the whole area not changing use – when using the higher estimate of 5.1 Gt of emissions from stopping both deforestation and forest degradation.

[39] Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S. and Turner, R. K., 2014. Changes in the global

value of ecosystem services. *Global Environmental Change*, 26. 152–158. DOI:10.1016/j.gloenvcha.2014.04.002. The average value of carbon benefits is obtained from the supplementary materials available online at the reference given here. Non-carbon ecosystem services include 15 other services ranging from water regulation to pollination and food production.

[40] See the International Resource Panel Report (in conjunction with UN REDD+) at: http://www.un-redd.org/IRPReport/tabid/132330/Default.aspx.

[41] Food and Agriculture Organization of the United Nations (FAO), 2010. *Global Forest Resources Assessment 2010*. Rome. Available at: http://www.fao.org/forestry/fra2010/.

[42] This is based on assuming US$1,000–2,000/ha once every 20+ years for wood harvesting. Returns per hectare for harvesters of trees vary greatly, but were in the range of US$800–1,000/ha in both the Brazilian Amazon and the US Pacific Northwest in the late 2000s (see the detailed Ohio State University GTAP database by region at: http://aede.osu.edu/research/forests-and-land-use/global-timber-market-and-forestry-data-project). An independent mean value of standing timber in the Amazon from a detailed assessment in 2012 was US$813/ha.

See: Ahmed, S. E. and Ewers, R. M., 2012. Spatial Pattern of Standing Timber Value across the Brazilian Amazon. *PLoS ONE*, 7(5). e36099. DOI:10.1371/journal.pone.0036099.

[43] Eliasch, J., 2008. *Climate Change: Financing Global Forests – the Eliasch Review*. Her Majesty's Government, London. Available at: https://www.gov.uk/government/publications/climate-change-financing-global-forests.

[44] This is based on a ceiling of 1 million hectares of degraded agricultural landscape that could reasonably be expected to be brought into restoration projects for the first time each year through intensive projects, providing a total of 15 million hectares in net area added over 15 years.

[45] A World Bank evaluation of the Loess Plateau projects in 2005 estimated 6.25 t/ha in net CO_2e savings per year which we use as an average: 0.09 Gt CO_2e/year = 6.25 X 20 X 50,000 X 15.

See: The World Bank, 2005. *China – Second Loess Plateau Watershed Rehabilitation Project*. Report No. 34612. Washington, DC. Available at: http://documents.worldbank.org/curated/en/2005/12/6547341/china-second-loess-plateau-watershed-rehabilitation-project.

A separate Chinese evaluation report found higher carbon sequestration rates. See: Cooper, P. J. M., Cappiello, S., Vermeulen, S. J., Campbell, B. M., Zougmoré, R. and Kinyangi, J., 2013. *Large-Scale Implementation of Adaptation and Mitigation Actions in Agriculture*. CCAFS Working Paper No. 50. CGIAR Research Program on Climate Change, Agriculture and Food Security. Available at: http://hdl.handle.net/10568/33279.

[46] See: Pye-Smith, C., 2013. *The Quiet Revolution: how Niger's farmers are re-greening the parklands of the Sahel*. ICRAF Trees for Change, No. 12. World Agroforestry Center, Nairobi. Available at: http://www.worldagroforestry.org/downloads/publications/PDFs/BL17569.PDF.

Also: Sendzimir, J., Reij, C. P. and Magnuszewski, P., 2011. Rebuilding Resilience in the Sahel: Regreening in the Maradi and Zinder Regions of Niger. *Ecology and Society*, 16(3), Art. 1. DOI:10.5751/ES-04198-160301.

[47] Niles, J. O., Brown, S., Pretty, J., Ball, A. S. and Fay, J., 2002. Potential carbon mitigation and income in developing countries from changes in use and management of agricultural and forest lands. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 360(1797). 1621–1639. DOI:10.1098/rsta.2002.1023.

[48] Verdone, M., Maginnis, S. and Seidl (forthcoming). *Re-examining the role of landscape restoration in REDD+*. International Union for Conservation of Nature (draft).

[49] See: World Resources Institute, 2008. *World Resources 2008: Roots of Resilience – Growing the Wealth of the Poor*. Produced by WRI in collaboration with United Nations Development Programme, United Nations Environment Programme, and the World Bank. Washington, DC. Available at: http://www.wri.org/publication/world-resources-2008.

Also see: Sendzimir et al., 2011, *Rebuilding resilience in the Sahel*, and Pye-Smith, C., 2013, *The Quiet Revolution*, both cited above.

[50] See: The World Bank, 2005, *China – Second Loess Plateau Watershed Rehabilitation Project*, cited above.

[51] Parry, A. et al., 2014 (forthcoming). *Strategies to achieve economic and environmental gains by reducing food waste*. New Climate Economy contributing paper. WRAP, Banbury, UK.

[52] WRAP, 2013. *Household Food and Drink Waste in the United Kingdom 2012*. Available at: http://www.wrap.org.uk/sites/files/wrap/hhfdw-2012-summary.pdf.

[53] See Table 11.4 in: Smith, P. and Bustamante, M., 2014. Chapter 11: Agriculture, Forestry and Other Land Use (AFOLU). In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, et al. (eds.). Cambridge University Press, Cambridge, UK, and New York. Available at: http://www.mitigation2014.org.

[54] Food and Agriculture Organization of the UN (FAO), 2013. *Food Wastage Footprint: Impacts on Natural Resources*. Summary Report. Rome.

Available at: http://www.fao.org/docrep/018/i3347e/i3347e.pdf.

[55] WRAP, 2013. *Household Food and Drink Waste in the United Kingdom 2012*. Available at: http://www.wrap.org.uk/content/household-food-and-drink-waste-uk-2012.

[56] See: International Energy Agency (IEA), 2013. *World Energy Outlook 2013*. Paris. Available at: http://www.worldenergyoutlook.org/publications/weo-2013/.

[57] The current policies scenario sees coal maintain a 40% share of new electricity generation worldwide, slow phase-out of established coal fleets in much of the world, and continued growth of coal in industry. Electricity generation from coal in 2030 amounts to 14,700 TWh, an increase of more than 5,000 TWh on current levels. See IEA, 2013, *World Energy Outlook 2013*, cited above.

[58] This is also supported by the Commission's work on stranded assets, see: Climate Policy Initiative, forthcoming. *Moving to a Low Carbon Economy: The Impact of Different Transition Policy Pathways on the Owners of Fossil Fuel Resources and Assets*. Available at: http://climatepolicyinitiative.org/publication/moving-to-a-low-carbon-economy/.

[59] International Renewable Energy Agency (IRENA), 2014. *REmap 2030: A Renewable Energy Roadmap*. Abu Dhabi. Available at: http://irena.org/remap/.

[60] International Energy Agency (IEA), 2012. *World Energy Outlook 2012*. Paris. Available at: http://www.worldenergyoutlook.org/publications/weo-2012/.

[61] Specifically, the "efficient world" scenario sees potential by 2035 to reduce coal use relative to the 2012 NPS of 923 Mtoe of coal use, which corresponds to 3.4 Gt CO_2e. Of this, just over 85% would be in place in 2030, resulting in 2.9 Gt CO_2e.

[62] The IEA stresses in its documentation of the "efficient world" scenario that, while the total amount of energy efficiency improvement is similar to that in the "450" scenario, they are assumed to come about through different mechanisms; they represent different, integrated scenarios. This raises the more general point that attribution of emissions reductions in an integrated scenario that contains both energy efficiency improvements (and thus "avoided" new coal use) and fuel switching (and thus reduced carbon intensity of new energy use) can be done in different ways. There is no obvious single correct method. In our decomposition we start with fuel switching, and treat emissions reductions attributable to energy efficiency as a residual. However, such an outcome is likely only if supporting policy, such as a carbon price, is implemented so that reduced demand from efficiency does not result in a reduction of low-carbon sources instead.

[63] The IEA assumes an aggregate rebound of 9%. However, some literature estimates have suggested higher numbers, including as much as 30% for direct rebound, with the potential for higher numbers once economy-wide effects are accounted for. However, such estimates are fraught with methodological difficulties, and the extent of rebound depends on multiple factors, including what other policy is implemented. In addition, rebound can in itself be welfare-enhancing, in the sense that it leaves end-users better off than they would have been without the option to adjust their consumption patterns in response to a change in the effective relative prices of energy services. For a discussion of rebound magnitudes and methodological issues, see: Sorrell, S., 2007. *The Rebound Effect: An Assessment of the Evidence for Economy-wide Energy Savings from Improved Energy Efficiency*. UK Energy Research Centre, London. Available at: http://www.ukerc.ac.uk/publications/the-rebound-effect-an-assessment-of-the-evidence-for-economy-wide-energy-savings-from-improved-energy-efficiency.html.

[64] As discussed in the main NCE report, levelised cost captures only a portion of the relevant comparison, as it is also necessary to account for the variation in value of electricity delivered at different time periods and locations, as well as additional costs that the use of variable renewables impose on the wider electricity system.

[65] *REmap* 2030 uses a baseline with renewable generation similar to the IEA "current policies" scenario that is used as a baseline also in this analysis. The 1,800–3,200 TWh cited is based on subtracting the 1,300 TWh in the NPS from the total estimated cost-effective potential identified in the *REmap* analysis. Note that arriving at these percentages requires an interpretation of the *REmap* 2030 cost curve and other materials, so has some margin for error. A greater source of uncertainty here arises from different valuations of avoided air pollution.

[66] The IRENA analysis is based on external cost of power generation from a 2005 study, whereas more recent literature suggests much higher mortality from exposure to the relevant pollutants and therefore higher external costs of air pollution from power generation. Methodological choices also heavily influence the costs calculated, and can give significantly higher external costs than in the source used for the IRENA study. Three NCE background papers discuss these issues in greater detail.

See: Hamilton, K., Brahmbhatt, M., Bianco, N. and Liu, J. M., 2014 (forthcoming). *Co-benefits and Climate Action*. New Climate Economy contributing paper. World Resources Institute, Washington, DC. Also: Kuylenstierna, J. C. I., Vallack, H. W., Holland, M., Ashmore, M., Schwela, D., Wei Wan, T. S., Whitelegg, J., Amann, M. and Anenberg, S., 2014 (forthcoming). *Air Pollution Benefits of Climate Strategies*. And: Parry, I., 2014. *Ancillary Benefits of Carbon Pricing*. New Climate Economy contributing paper. International Monetary Fund. All three to be available at: http://newclimateeconomy.report.

[67] For example, see: Ryan, L. and Campbell, N., 2012. *Spreading the Net: The Multiple Benefits of Energy Efficiency Improvements*. International Energy Agency Insights Series 2012. OECD Publishing, Paris. Available at: http://www.iea.org/publications/insights/ee_improvements.pdf.

[68] For example, see: Allcott, H. and Greenstone, M., 2012. Is there an Energy Efficiency Gap? *Journal of Economic Perspectives*, 26. 3–28. DOI:

10.1257/jep.26.1.3.

[69] US Environmental Protection Agency (EPA), 2014. *Global Mitigation of Non-CO2 Greenhouse Gases: 2010–2030*. Executive Summary. Available at: http://www.epa.gov/climatechange/Downloads/EPAactivities/MAC_Report_2014-Exec_Summ.pdf.

[70] See: Brandt, A. R. et al., 2014. Methane Leaks from North American Natural Gas Systems. *Science*, 343(6172). 733–735. DOI:10.1126/science.1247045. See also: Caulton, D. R. et al., 2014. Toward a better understanding and quantification of methane emissions from shale gas development. *Proceedings of the National Academy of Sciences*, 111(17). 6237–6242. DOI:10.1073/pnas.1316546111.

[71] A New Climate Economy background paper provides a detailed account of air pollution impacts; see: Kuylenstierna, J. C. I., Vallack, H. W., Holland, M., Ashmore, M., Schwela, D., Wei Wan, T. S., Whitelegg, J., Amann, M. and Anenberg, S., 2014 (forthcoming). *Air Pollution Benefits of Climate Strategies*. To be available at: http://newclimateeconomy.report.

[72] International Energy Agency (IEA), 2013. *Redrawing the Energy-Climate Map. World Energy Outlook Special Report*. Paris. Available at: http://www.worldenergyoutlook.org/energyclimatemap/.

[73] International Energy Agency (IEA), 2011. *World Energy Outlook 2011*. Paris. Available at: http://www.worldenergyoutlook.org/publications/weo-2011/.

[74] The source reports abatement only for 2020 and 2035. The 2.3 Gt abatement potential, as well as other numbers presented here, is a linear interpolation between those two years for 2030. We make no adjustment for differences in the baseline numbers underlying the 2011 and 2013 editions of the *World Energy Outlook*, as differences between the two are small relative to the size of the range we present here.

[75] Hydrofluorocarbons (HFCs) are intentionally made to replace stratospheric ozone-depleting substances (ODS), in such applications as air conditioning, refrigeration, solvents, foam blowing and aerosols. Although they do not deplete the ozone layer, they are potent greenhouse gases. HFCs are projected to grow very rapidly and are the fastest-growing greenhouse gas in many countries, including in the US, China and India.

[76] See: UNEP, Climate and Clean Air Coalition, Definitions of short-lived climate pollutants. Available at: http://www.unep.org/ccac/Short-LivedClimatePollutants/Definitions/tabid/130285/Default.aspx.

[77] For full details of the Velders estimates, see: Velders, G. J. M., Fahey, D. W., Daniel, J. S., McFarland, M. and Andersen, S. O., 2009. The large contribution of projected HFC emissions to future climate forcing. *Proceedings of the National Academy of Sciences*, 106. 10949–10954. DOI: 10.1073/pnas.0902817106.

[78] See: Brushan, C., 2014. T*hematic Paper Phasing-out Hydrofluorocarbons in South Asia: Issues and way ahead.* Climate Action Network South Asia, Bangladesh. Available at: http://cansouthasia.net/?download=2126.

Further details estimated from: US Environmental Protection Agency, 2012. *Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990–2030*. Available at: http://www.epa.gov/climatechange/Downloads/EPAactivities/Summary_Global_NonCO2_Projections_Dec2012.pdf.

[79] ClimateWorks and European Climate Foundation, 2011. *Abatement opportunities for non-CO2 climate forcers: Black carbon, methane, nitrous oxide and f-gas emissions reductions to complement CO2 reductions and enable national environmental and social objectives*. Project Catalyst Briefing Paper, May 2011. Available at: http://www.project-catalyst.info/images/publications/final%20report%20non-co2%20climate%20forcers.pdf.

[80] World leaders recognised the threat posed by the growth of HFCs in the outcome document of the Rio +20 Summit in 2012 and called for the gradual phase-down of the production and consumption. Six countries, with the support of more than 100 others, have submitted proposals to undertake such a phase-down under the Montreal Protocol. Support for this approach is growing rapidly, including from the leaders of the G20 largest economies.

[81] United Nations Environment Programme (UNEP) and the Technology and Economic Assessment Panel (TEAP), 2010. *Montreal Protocol on Substances that deplete the Ozone Layer, TEAP 2010 Progress Report, Volume 1*. Available at: http://www.unep.ch/ozone/assessment_Panels/TEAP/Reports/TEAP_Reports/teap-2010-progress-report-volume1-May2010.pdf. ("Systems using low-GWP alternatives are able to achieve equal or superior energy efficiency in a number of sectors, such as domestic refrigeration, commercial refrigeration and some types of air-conditioning systems. In the case of industrial refrigeration, for example, hydrocarbon and ammonia systems are typically 10–30% more energy efficient than conventional high-GWP HFC systems."). Also: Schwarz, W. et al., 2011. *Preparatory study for a review of regulation (EC) No 842/2006 on certain fluorinated greenhouse gases. Annexes to the Final Report*. European Commission. Available at: http://ec.europa.eu/clima/policies/f-gas/docs/2011_study_en.pdf.

[82] Schwarz, W., Gschrey, B., Leisewitz, A., Herold, A., Gores, S., Papst, I. et al., 2011. *Preparatory study for a review of regulation (EC) No 842/2006 on certain fluorinated greenhouse gases*. Final report. Prepared for the European Commission in the context of Service Contract No 070307/2009/548866/SER/C4. Available at: http://ec.europa.eu/clima/policies/f-gas/docs/2011_study_en.pdf.

[83] For example, in the room air conditioning sector, a recent study concluded that significant energy savings are cost-effective in most of the economies studied. Shah, N., Waide, P. and Phadke, A., 2013. *Cooling the planet: opportunities for deployment of super-efficient room air*

conditioners. Berkley Lab, Department of Energy. Available at: https://isswprod.lbl.gov/library/view-docs/private/output/rpt82580.PDF.

[84] Zaelke, D., Borgford-Parnell, N., Andersen, S. O., Sun, X., Clare, D., Phillips, C., Herschmann, S., Peng Ling, Y. and Milgroom, A., 2014. *IGSD Primer on Hydrofluorocarbons*. IGSD Working Paper: June 2014. Institute for Governance & Sustainable Development. Available at: http://www.igsd.org/documents/HFCPrimerJune2014_010.pdf.

[85] Zaelke et al., 2014. *IGSD Primer on Hydrofluorocarbons*.

[86] Global e-Sustainability Initiative and the Boston Consulting Group, 2012. *GeSI SMARTer 2020*. Available at: http://gesi.org/SMARTer2020.

[87] Rogers, E. A., 2014. *The Energy Savings Potential of Smart Manufacturing. American Council for an Energy-Efficient Economy*, Washington, DC. Available at: http://www.aceee.org/sites/default/files/publications/researchreports/ie1403.pdf.

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ABOUT THE NEW CLIMATE ECONOMY

The Global Commission on the Economy and Climate is a major new international initiative to examine the economic benefits and costs of acting on climate change. Chaired by former President of Mexico Felipe Calderón, the Commission comprises former heads of government and finance ministers, and leaders in the fields of economics, business and finance.

The New Climate Economy (NCE) is the Commission's flagship project. It provides independent and authoritative evidence on the relationship between actions which can strengthen economic performance and those which reduce the risk of climate change. It reported in September 2014 in advance of the UN Climate Summit. It aims to influence global debate about the future of economic growth and climate action.