Box 2.1 ▷ Mitigating short-lived climate pollutants

Short-lived climate pollutants (SLCPs) are substances with a lifetime in the atmosphere ranging from a few days to several decades that mainly affect the climate in the (relatively) short term. CO_2 emissions, by contrast, affect the climate system over a much longer time horizon. SLCPs are responsible for a substantial fraction of the radiative forcing to date. The major SLCPs are black carbon, methane, tropospheric ozone and some hydro fluorocarbons (HFCs). Black carbon is produced by the incomplete combustion of fossil fuels and biomass, and is a primary component of particulate matter and particulate air pollution. In 2010, household air pollution and ambient outdoor particulate matter pollution were estimated to have caused, respectively, over 3.5 and 3.2 million premature deaths (Lim, *et al.*, 2012). According to the United Nations Environment Programme (UNEP), black-carbon emissions are expected to remain stable overall through 2030, decreasing in OECD countries and increasing in non-OECD countries (UNEP, 2011).

Although the adoption of strategies to reduce SLCPs (with the exception of methane)[4] are not considered in the 4-for-2 °C Scenario, recent studies have identified sixteen mitigation measures related to SLCPs which use technologies and practices that already exist (UNEP/WMO, 2011; UNEP, 2011). These studies estimate that the adoption of such measures by 2030 would reduce the warming expected by 2050 by 0.4-0.5 °C (and, in the Arctic, by about 0.7 °C even in 2040), while each year preventing more than two million premature deaths and over 30 Mt of crop losses. There could be associated reduced disruption of rainfall patterns.

Strategies that reduce emissions of SLCPs complement CO_2 mitigation by reducing short-term increases in temperature, thereby minimising the risk of dangerous climate feedbacks. However, lasting climate benefits from fast action on SLCPs are contingent on stringent parallel action on longer-lasting CO_2 emissions. In other words, while fast action to mitigate SLCPs could help slow the rate of climate change and improve the chances of staying below the 2 °C target in the near term, longer term climate protection depends on deep and persistent cuts in CO_2 emissions being rapidly realised.

Subsidies for fossil-fuel consumption lead to an inefficient allocation of resources and market distortion by encouraging excessive energy use. While they may have well-intentioned objectives, social ones for example, in practice they have usually proven to be an unsuccessful or inefficient means of achieving their goals. Moreover, they invariably have unintended negative consequences, such as encouraging wasteful and inefficient consumption, thereby contributing to climate change. The latest IEA estimates indicate that fossil-fuel consumption subsidies amounted to $523 billion in 2011, up almost

4. The methane emissions reduction measures discussed in the 4-for-2 °C Scenario also contribute to reduction of black carbon emissions and their effect on climate change (Stohl, *et al.*, 2013).

30% on 2010 and six times more than the global financial support given to renewables (IEA, 2012a). In those regions where the subsidies exist, this level of subsidy equates to an incentive of $110 per tonne CO_2 to consume fossil fuels. Fossil-fuel subsidies are often intended to improve access to modern energy services for the poor, but our analysis indicates that only 8% of the subsidy granted typically reaches the poorest income group (IEA, 2011a). Political support for fossil-fuel subsidy reform has been building in recent years, and G20 and APEC (Asia-Pacific Economic Cooperation) member economies have made commitments to phase out inefficient fossil-fuel subsidies and many are now moving ahead with implementation. In the 4-for-2 °C Scenario, recognising the political challenge involved in subsidy phase-out, we assume, as in the New Policies Scenario of *WEO-2012*, a total subsidy phase-out by 2020 in fossil-fuel importing countries; but in exporting countries (where sustained reforms are likely to be even more difficult to achieve) subsidisation rates are only reduced by an additional 25% by 2020, relative to the New Policies Scenario, with subsidies completely removed by 2035.[5] Average end-use prices in net-exporting regions remain significantly lower than in many other parts of the world as we make no assumption that they introduce any new taxes or excise duties on energy. For example, average gasoline prices in the Middle East are around one-fifth of the OECD average in 2020.

Emissions abatement to 2020

Effective implementation of the proposed policy measures would have a profound impact on energy-related greenhouse-gas emissions. In the 4-for-2 °C Scenario, emissions are lower by 3.1 Gt (in CO_2-eq terms) in 2020, compared with the New Policies Scenario,[6] although they are still higher than today (Figure 2.2). Energy efficiency makes the largest contribution to abatement, at 1.5 Gt (or 49%) in 2020.[7] Contributions to abatement from restrictions on subcritical coal-fired power plants are around 640 Mt (21%), the reduction of methane emissions in upstream oil and gas production at more than 570 Mt (18%) and the partial phase-out of subsidies to fossil fuels consumed by end-users at more than 360 Mt (12%). In each case, these savings come on top of those assumed in the trajectory resulting from policies that are already adopted or under consideration by governments (the New Policies Scenario).

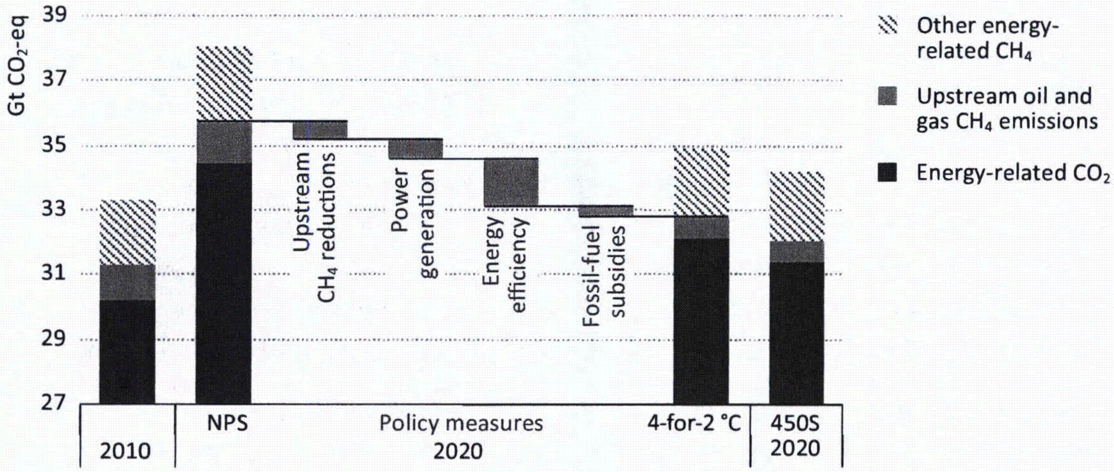
5. Subsidisation rate is calculated as the difference between the full cost of supply and the end-user price, expressed as a proportion of the full cost of supply. For countries that import a given product, subsidy estimates are explicit. In contrast, for countries that export a given product, subsidy estimates represent the opportunity cost of pricing domestic energy below market levels.

6. All emission reductions in this section are presented relative to the New Policies Scenario, unless indicated otherwise.

7. Energy efficiency-related savings in 2020 take account of the rebound effect, *i.e.* the effect of increased use of a product or facility as a result of efficiency-related operating costs savings or higher disposable income from reduced energy expenditures. The rebound effect in the 4-for-2 °C Scenario is largely related to decreases in consumer prices as GDP does not change in comparison to the New Policies Scenario, but is counterbalanced by the assumed fossil-fuel subsidy phase-out that leads to increased energy conservation.

The assumed policy measures go a long way toward closing the gap between expected emissions levels in 2020 on the basis of present government intentions, as modelled in the New Policies Scenario, and those required to achieve the 2 °C target (the 450 Scenario). They avoid 80% of the difference in emissions levels. Nonetheless, a gap of around 770 Mt still remains, indicating that yet more stringent measures will be required after 2020 in order ultimately to meet the 2 °C goal.

Figure 2.2 ▷ Change in world energy-related CO_2 and CH_4 emissions by policy measure in the 4-for-2 °C Scenario



Notes: Methane emissions are converted to CO_2-eq using a Global Warming Potential of 25. NPS = New Policies Scenario; 450S = 450 Scenario.

More than 70% of abatement occurs in non-OECD countries, where projected demand for energy in 2020 is around 480 million tonnes of oil equivalent (Mtoe) (or 5%) lower than in the New Policies Scenario (Figure 2.3). China alone is responsible for more than one-quarter of the global emissions savings from these measures in 2020, resulting from the significant scope to reduce emissions that accompanies its rapidly rising energy demand, large potential to further improve energy efficiency and heavy reliance on coal-fired power generation. The Middle East (9% share of savings in 2020) and India (9%) together account for almost one-fifth of the savings, driven primarily by fossil-fuel subsidy reform and reduced upstream methane emissions in the former and efficiency improvements and changes in the power generation mix in the latter. Although energy efficiency policy plays an important role in the Middle East too, it is the assumed enhanced phase-out of fossil-fuel subsidies that encourages its realisation, as this reduces the payback period of more efficient technologies to the necessary extent to make efficiency policy viable.[8] OECD countries see a smaller share of the savings at below 30%, although the United States (13% share of savings in 2020) is the second-largest contributor to emissions reductions,

8. For example, given heavily subsidised low petrol prices in Saudi Arabia, the payback period for a car that consumes half as much fuel per 100 kilometres as today's average car is currently close to twenty years.

after China, and, together with the European Union (8%), accounts for around one-fifth of the global total. The larger share of savings in non-OECD countries is directly linked to the higher growth in their energy demand – 90% of global demand growth to 2020 in the New Policies Scenario. With energy demand per capita today 70% below the OECD average, non-OECD countries have expectations of higher growth to 2020 in both energy demand and emissions – and associated scope for savings – especially because population growth (90% of global growth to 2020) and economic growth (almost three-quarters of global GDP growth until 2020) are much stronger than in OECD countries.

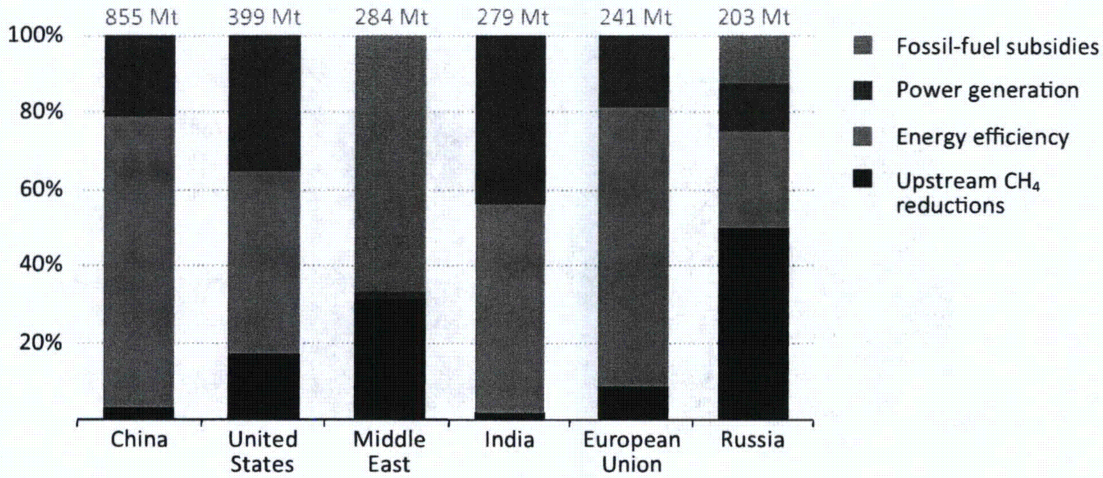
Box 2.2 ▷ The role of renewables in the 4-for-2 °C Scenario

In many countries, renewables deployment is driven by government targets. Examples include the targeted share of 20% in total energy demand by 2020 in the European Union; US state-level renewable portfolio standards, covering 30 states and the District of Columbia; existing capacity targets by technology type in China, India and Brazil; and biofuels blending mandates in many countries. A wide variety of such policies and mechanisms are in place today. All are taken into account in the New Policies Scenario, the central scenario of *WEO-2012*. They include the enforcement and further strengthening of these policies where governments have announced this intention.

Renewable energy accordingly plays an important role in all our scenarios, in particular in power generation. Though not characterised specifically as one of the additional policies of the 4-for-2 °C Scenario, the share of renewables in global power generation increases from 20% today to 27% in 2020. This is two percentage points above the level reached in the New Policies Scenario, due to the proposed policy to reduce the use of inefficient coal-fired power generation and lower electricity demand from energy efficiency policies. In net terms, renewables meet about 60% of the increase in global electricity demand up to 2020 in the 4-for-2 °C Scenario, installed capacity reaching around 1 350 gigawatts (GW) of hydropower, 580 GW of wind, 265 GW of solar photovoltaic, 135 GW of biomass-fired power plants and 35 GW of other renewables. The 4-for-2 °C Scenario sees cumulative investment in renewables of $2.0 trillion up to 2020, contributing to the reduction in renewable energy technology costs post-2020, thereby facilitating steeper emissions reductions then.

Increasing deployment of renewables is supported by subsidies, which help overcome deployment barriers. In power generation, these subsidies are set to increase to $142 billion in 2020 in the 4-for-2 °C Scenario, up from $64 billion in 2011. This is 5% over the level reached in the New Policies Scenario in 2020 (due to lower wholesale electricity prices from lower international fuel prices), but is offset by the wider economic gains achieved from lower fossil-fuel prices. Biofuels (mostly supported by blending mandates) received subsidies totalling $24 billion in 2011; these rise to $47 billion in 2020 in the 4-for-2 °C Scenario. The European Union, United States and China account for the bulk of renewables subsidies, today (85%) and in 2020 (77%).

Figure 2.3 ▷ Change in energy-related CO_2 and CH_4 emissions in selected regions in the 4-for-2 °C Scenario relative to the New Policies Scenario, 2020



Note: Savings are allocated by enabling policy and total emissions are in CO_2-eq.

Abatement to 2020 by policy measure

Energy efficiency measures

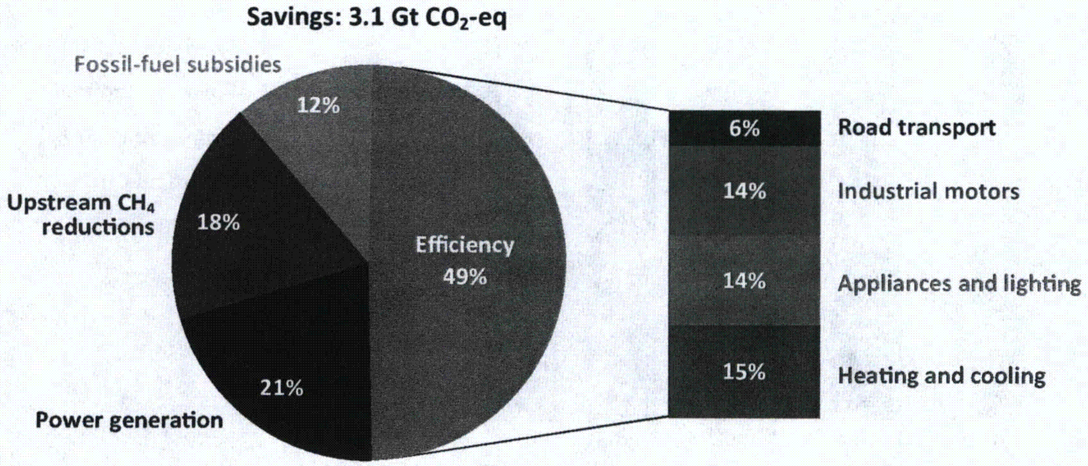
In the 4-for-2 °C Scenario, energy efficiency is the largest contributor to the reduction in global greenhouse-gas emissions, resulting in savings of 1.5 Gt CO_2-eq in 2020, or almost half of the total abatement relative to the New Policies Scenario (Figure 2.4). As indicated above, while there is a raft of efficiency policies capable of reducing energy consumption and therefore emissions,[9] we have focused on just four key measures on the basis that they can be quickly implemented and that the mechanics of implementation have already been developed in numerous countries. The selected policies are applied to new equipment and technologies: they exclude the early retirement of existing stock.

Key energy efficiency measures include:

- More efficient heating and cooling systems in residential and commercial buildings through minimum energy performance standards (MEPS) for new equipment, and technology switching, such as through greater use of heat recovery and better use of automation and control systems.
- More efficient appliances and lighting in residential and commercial buildings.
- Use of more efficient electric motor systems in industrial applications, such as pumping, compressing air, and other types of mechanical handling and processing.
- Fuel-economy standards and fuel-economy labelling for new passenger light-duty vehicles (PLDVs) and freight trucks in road transport.

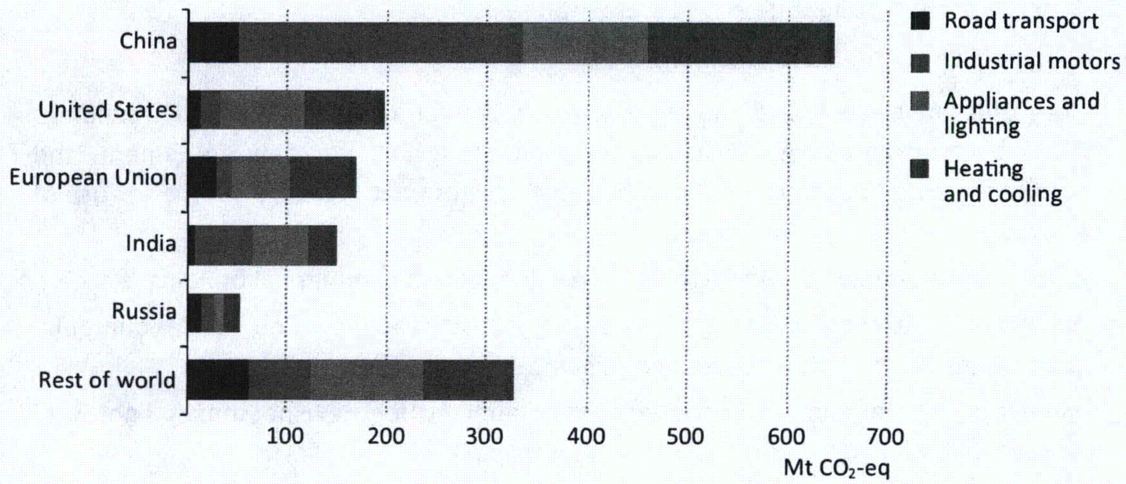
9. There are already numerous energy efficiency policies in place in many countries; an overview of key policies by country and sector is available in the energy efficiency focus in *WEO-2012* (IEA, 2012a). All figures here represent the additional gains resulting from the specified additional measures.

Figure 2.4 ▷ **Change in world CO_2 and CH_4 emissions in the 4-for-2 °C Scenario by policy measure relative to the New Policies Scenario, 2020**



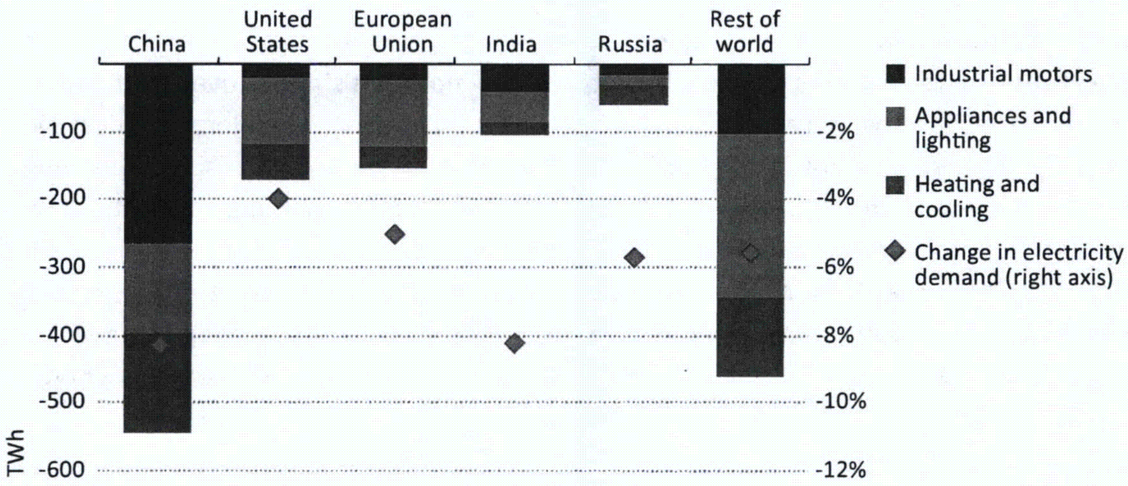
Among these measures, those targeting heating and cooling, appliances, lighting and industrial motors have a similar effect on reducing greenhouse-gas emissions, each contributing around 30% of the additional efficiency-related savings. Policies targeting road transport make up a smaller share of abatement, partly because of the lead times required for more efficient vehicles to penetrate the vehicle stock and because the New Policies Scenario takes into account the numerous policies already in place to improve efficiency in road transport (thus reducing the scope for further gains in the 4-for-2 °C Scenario).

Figure 2.5 ▷ **CO_2 and CH_4 savings due to improved efficiency by region and policy in the 4-for-2 °C Scenario relative to the New Policies Scenario, 2020**



Almost 80% of energy efficiency-related savings occurs in five regions: China, the United States, the European Union, India and Russia (Figure 2.5). China sees by far the largest reduction in emissions through more efficient use of energy, at around 40% of the global total. Many of these savings are made in industry, at around 280 Mt CO_2-eq in 2020, or 44% of efficiency-related savings, stemming from the use of more efficient industrial motor systems. Industry in China currently accounts for about two-thirds of the country's total electricity consumption, of which it is estimated that 60-70% is used by electric motors (IEA, 2011b). While China has already adopted MEPS for some motors, their typical operational efficiency is 10-30% below the standard in international best practices (SwitchAsia, 2013). The vast majority of electricity savings from motor systems, however, comes from a combination of appropriate use of variable speed drives, proper motor sizing, preventive maintenance and optimising the motor-driven equipment, as the nominal efficiency of an electric motor can only be enhanced by around three percentage points for a medium-sized motor. In China, a combination of further tightening of MEPS, their wider adoption and, particularly, the imposition of requirements for energy management systems could considerably reduce electricity demand and thereby emissions from the currently carbon-intensive power generation sector (Figure 2.6). India, too, has considerable potential for emissions reductions through the use of more efficient industrial motors. At present, India has no MEPS for electric motors in industry and a highly carbon-intensive power mix. The adoption of such standards in India is assumed in the 4-for-2 °C Scenario and lowers its emissions from the industry sector by about 55 Mt CO_2-eq in 2020 (almost 40% of the projected abatement related to energy efficiency). While MEPS are an important instrument to encourage the use of more efficient industrial motor systems, there are barriers to their deployment, such as inadequate assessment of the actual service required and the complexity of motor systems. However, much has already been done to study policy opportunities and policy best practices in this area, paving the way for the swift and effective introduction of this measure.[10] This results in widespread adoption of more efficient industrial motor systems in the 4-for-2 °C Scenario.

Figure 2.6 ▷ Reduction in electricity demand due to energy efficiency policies in the 4-for-2 °C Scenario relative to the New Policies Scenario, 2020



10. See for example IIP (2011) and IEA (2011b).

Efficient use of energy in buildings, including energy used for heating, cooling, appliances and lighting, has recently attracted considerable attention as policies in place or under consideration tap only around one-fifth of the economic potential (IEA, 2012a). In 2013, for example, the Major Economies Forum initiated a dialogue among its member countries with a view to their setting voluntary intensity targets for energy consumption in buildings. In terms of heating and cooling, installing more efficient equipment (such as gas heating systems, heat pumps and high efficiency air-conditioners) is one of the best means of reducing emissions in the short term, although the potential to improve the building envelope is also vast (IEA, 2013b). Several countries have already adopted voluntary programmes, *e.g.* India or Brazil, or binding ones, such as the United States, to advance uptake of more efficient equipment.

In the 4-for-2 °C Scenario, China achieves 40% of the global emissions reduction related to more efficient heating and cooling systems. The high share reflects the expected rapid increase in projected demand in China for such services, particularly for air-conditioning, which means that the adoption of MEPS can significantly curtail growth in energy demand. The United States and the European Union are together responsible for a further one-third of the global emissions reductions related to more efficient heating and cooling equipment. In both cases, the deployment of new higher efficiency heating and cooling systems has a significant impact on emissions, bringing reductions of almost 80 Mt CO_2-eq and 65 Mt CO_2-eq in 2020 for the United States and the European Union, respectively.

Just as for industrial motors, there are barriers to the use of more efficient heating and cooling systems. While MEPS are an important means of achieving emissions reductions in the 4-for-2 °C Scenario, they need to be accompanied by policies to ensure their enforcement. Typical barriers include public acceptance and other general market risks of new technologies, and can be related to a shortage of skilled labour in some countries. Split incentives are another problem that needs careful attention.[11] Providing information through awareness campaigns and training programmes can be helpful tools to overcome these barriers.

There is considerable scope in all regions to reduce emissions stemming from the use of appliances and lighting. This is linked, in part, to their important share in overall electricity demand today: lighting and appliances alone are responsible for 37% of electricity demand in OECD countries and 26% in non-OECD countries. Due to the relatively short operating lifespan of the equipment concerned, MEPS for appliances and lighting are particularly effective and are already widely used in many countries. Most OECD countries have adopted such standards for a wide range of products, as has China. Russia is phasing out incandescent light bulbs (100 watts and above), while India is set to adopt mandatory standards and labelling for room air conditioners and refrigerators. At the Clean Energy

11. A split incentive refers to the potential difficulties in motivating one party to act in the best interests of another when they may have different goals and/or different levels of information.

Ministerial in New Delhi in April 2013, ministers highlighted the importance of the Super-efficient Equipment and Appliance Deployment (SEAD) initiative as a means to progress quickly and cheaply towards a more sustainable future.[12]

In the 4-for-2 °C Scenario, the contribution of appliances and lighting to additional energy efficiency-related savings is particularly large in the United States, at 44% in 2020. The bulk of these savings could be achieved by tightening the MEPS that already exist. Appliances and lighting are responsible for close to 40% of the efficiency-related savings in India, a high share that reflects the current dearth of efficiency standards. In absolute terms, the largest reductions are made in China (125 Mt CO_2-eq), followed by the United States (around 85 Mt) and the European Union (around 60 Mt), where we assume that the new EcoDesign Directive that covers fifteen product groups is further strengthened. Across all countries, there is still considerable potential to expand both the range of products that are covered by MEPS and the stringency of the standards.

Road transport, which is currently responsible for around 16% of CO_2 emissions from the energy sector, has received a lot of policy attention in recent years, as high oil prices and rising demand for mobility have strengthened the case for efficiency improvements. Many governments have adopted fuel-economy policies in a bid to reduce the burden on consumers and the cost of oil imports. PLDV standards have been adopted most widely, including in many of the major car markets in OECD countries (IEA, 2012b). Outside OECD countries, only China has adopted such standards, though India plans to do so. Fuel-economy standards for trucks are also increasingly receiving the attention of policy makers and have been adopted in several OECD countries. Though essential to realising fuel efficiency in road transport, standards are and should be complemented by supporting policies to overcome the barriers associated with their deployment, such as information gaps.[13]

In the 4-for-2 °C Scenario, the impact of tighter fuel-economy standards, *i.e.* beyond those implemented in the New Policies Scenario, is moderate in the period to 2020, compared with the other energy efficiency measures proposed. This reflects the time it takes for the full effect of fuel-economy standards for new vehicles to be felt across the entire fleet. By contrast, they have a much greater impact after 2020. The relatively limited impact also reflects the fact that fuel-efficiency regulations are already in place in many of the major economies. Nonetheless, fuel-efficiency standards in road transport do play a significant role in the overall abatement: in Russia, they account for about 30% of the efficiency-related savings, compared with the New Policies Scenario. In the 4-for-2 °C Scenario, the average tested fuel efficiency of new PLDV sales in 2020 reaches around 40 miles per gallon (mpg) (or 5.9 litres per 100 kilometres [l/100km]) in the United States; 95 grammes of CO_2 per kilometre (g CO_2/km) in Europe (or 3.8 l/100km); 5.0 l/100km in China; and 4.8 l/100km in India. The global average is 5.1 l/100km.

12. For more information, see *www.superefficient.org*.

13. For an overview of suitable policy packages, see IEA (2012b).

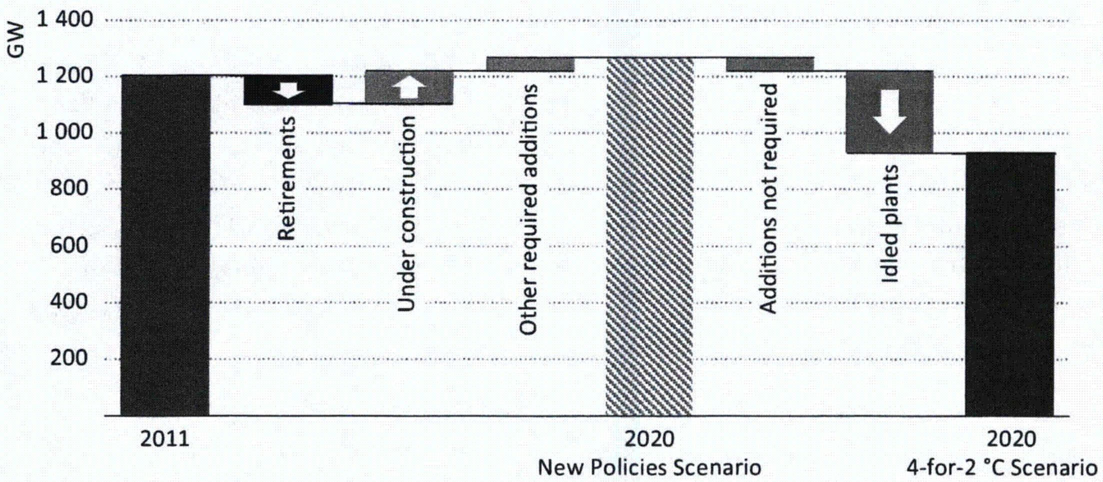
Reducing the use of inefficient coal-fired power plants

In the 4-for-2 °C Scenario, the use of the least efficient coal-fired power plants is reduced, relative to the New Policies Scenario. We assume a ban is introduced prohibiting the construction of new subcritical coal-fired power plants. Plants that have recently been built or are already under construction and have therefore yet to recover their investment cost, continue to operate, albeit at reduced levels. Those inefficient plants that have already repaid their investment costs are either retired or idled. Possible levers to achieve this policy include:

- Adoption of energy efficiency or CO_2 emissions standards for coal-fired power plants.
- Adoption of air pollution standards.
- Pricing the use of carbon, for example through an emissions trading scheme.
- Assigning power production limits for each generator to incentivise the use of the most efficient plants (typically in liberalised markets).
- Allocation of generation slots, renewing (or not) operational licences or altering the dispatch schedule in favour of more efficient plants (typically in regulated markets).

As a result of the proposed policy, the global installed capacity of subcritical power plants in operation decreases by more than one-fourth in 2020, or about 340 gigawatts (GW), compared with the New Policies Scenario (Figure 2.7). Existing plants account for the vast majority of this reduction: while 170 GW of new subcritical plants are added in the New Policies Scenario by 2020, only about 50 GW of them are not already under construction and therefore do not go ahead in the 4-for-2 °C Scenario. Of the 1 270 GW of subcritical coal-fired power plants in 2020 in the New Policies Scenario, 290 GW with the lowest efficiencies are either retired or not used at all by 2020. A more complete phase-out of coal subcritical plants by 2020 is unrealistic in most regions both because it would unacceptably reduce the reliability of electricity supply and because of the costs involved.

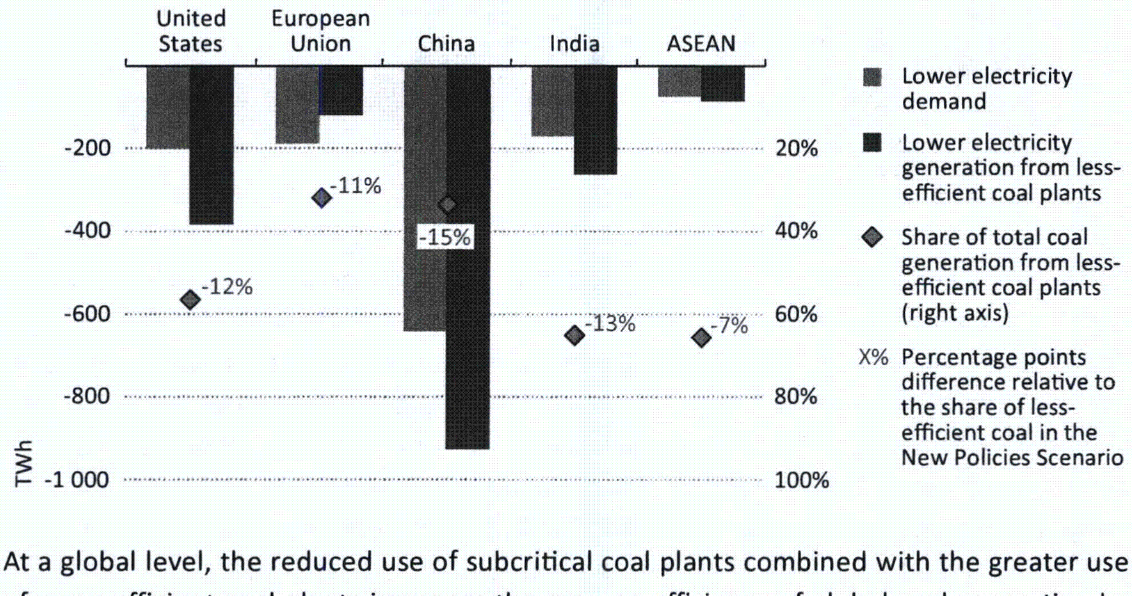
Figure 2.7 ▷ Change in subcritical coal electrical capacity in the New Policies and the 4-for-2 °C Scenarios, 2020



The extent of the potential reduction in use of inefficient coal plants by region is determined by two main factors: the extent of the reduction of electricity demand (which is achieved through the proposed energy efficiency measures in the 4-for-2 °C Scenario) and the extent of the opportunity to switch to other technologies. The switch in power generation is mostly possible to gas-fired power plants or more efficient coal plants up to 2020, as the additional reliance on nuclear power is constrained by long construction lead times and the New Policies Scenario already embodies rapid growth in renewables, mainly driven by targets in many countries (Box 2.2). The decrease of electricity demand generally provides an opportunity to reduce the use of subcritical coal plants by at least the same amount.

The possibility of switching to other, more efficient, technologies depends on several factors, which include the existing capacity mix, the extent of the need for capacity additions, the nature of the support schemes in place, the relative efficiency of the plants available and the construction periods for new plants. For example, in China and in the United States, the reduction of power generation from inefficient coal plants in the 4-for-2 °C Scenario is greater than the reduction in electricity demand, due to the possibility to switch to more efficient coal technologies and gas-fired generation (Figure 2.8). In Europe, on the other hand, the CO_2 price assumed in the New Policies Scenario already provides an incentive for higher-efficiency power plants, which limits the scope for additional production from these plants in the 4-for-2 °C Scenario, with the result that the fall in the use of coal plants fails to keep pace with the reduction in electricity demand.

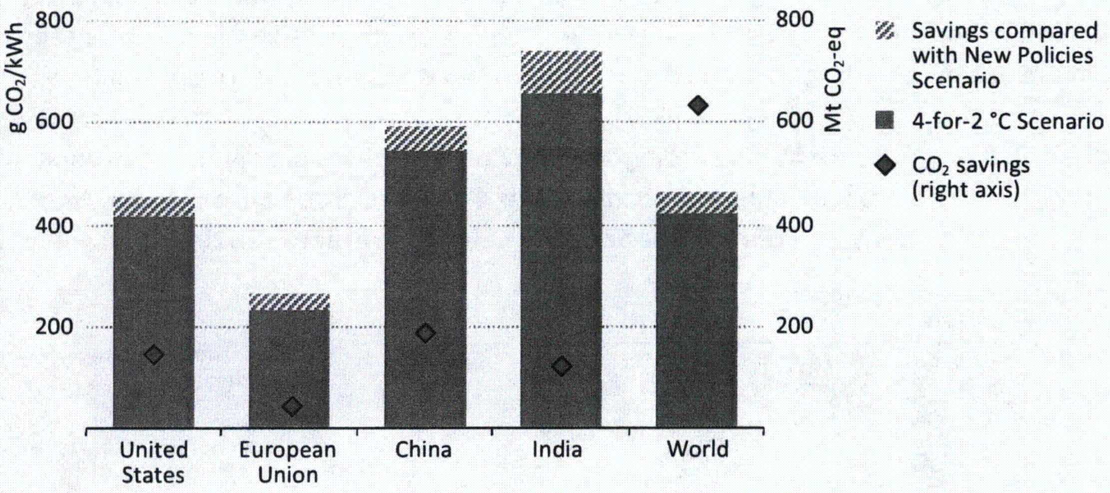
Figure 2.8 ▷ Change in electricity demand and coal-fired power generation from less-efficient plants in the 4-for-2 °C Scenarios relative to the New Policies Scenario by selected regions, 2020



At a global level, the reduced use of subcritical coal plants combined with the greater use of more efficient coal plants increases the average efficiency of global coal generation by 3.3 percentage points in 2020 in the 4-for-2 °C Scenario, relative to 2011. This is more than twice as high as the efficiency gain achieved in the New Policies Scenario, where the average efficiency of the coal power plant fleet increases by 1.5 percentage points over the same period.

The reduced use of inefficient coal-fired power plants in the 4-for-2 °C Scenario cuts global CO_2 emissions by around 570 Mt in 2020, relative to the New Policies Scenario, as the average emissions intensity of power generation is almost 10% lower, at about 420 grammes of CO_2 per kilowatt-hour (g CO_2/kWh) (Figure 2.9). Methane emissions from coal mining, transport and use, at around 70 Mt CO_2-eq, are also reduced as a result of the lower use of coal. In overall terms, the additional emissions savings are most pronounced in countries which currently have low average power plant efficiencies (such as India) or a large coal power fleet (such as the United States and China). They are the result of a sharp drop in coal capacity utilisation from 60% in 2011 to 54% in 2020, driven by a decline in the use of subcritical coal plants from 59% in 2011 to 39% in 2020. There is no scope for further reduction while maintaining reliability of electricity supply.

Figure 2.9 ▷ Average power generation emissions intensity and corresponding CO_2 and CH_4 savings in the 4-for-2 °C Scenario relative to the New Policies Scenario, 2020



Relative to the New Policies Scenario, almost 30% of global CO_2 and CH_4 emissions savings resulting from reduced use of inefficient coal plants occurs in China. China is increasingly suffering from the impact of local air pollution, partly caused by the substantial use of coal in power generation. According to recent analysis by the Chinese Academy for Environmental Planning (CAEP), the associated societal cost of environmental degradation, including health-related damage, amounted to the equivalent of 3.5% of GDP in 2010. In an attempt to improve the efficiency of its power sector, China phased out over 70 GW of small, inefficient coal-fired power capacity between 2006 and 2010 as part of its 11th Five-Year Plan. China has also tested further policy options for reducing emissions of air pollutants from coal power stations, including through the Energy Saving Dispatch Policy (ESDP) that was tested in five provinces in 2007 and 2008 (and that could help achieve the projected reduction in CO_2 emissions seen in the 4-for-2 °C Scenario). In China, power dispatch usually works according to predefined quotas allocated to generators by provincial governments, with generators receiving a fixed price for their power output and, in some cases, free-to-trade quotas to optimise the generation pattern. The ESDP sought to maximise the overall efficiency of fossil fuel-based power plants by allocating higher quotas to the most efficient units, without changing the compensation to power generators. The pilot phase raised a number of problems – such as challenges to system reliability – and was seen as only a temporary device before the eventual transition to a fully market-based power system as envisaged by the central government. But the scheme demonstrated how one policy to reduce the use of the least-efficient coal power stations can work in China. In addition to reducing growth in CO_2 emissions, the 4-for-2 °C Scenario also sees an improvement in local air quality in China: sulphur dioxide (SO_2) emissions from the use of coal in power generation are 9% lower than in the New Policies Scenario by 2020, nitrogen oxides (NO_x) emissions are 8% lower and particulate matter ($PM_{2.5}$) emissions are 3% lower.

Almost one-quarter of the global reduction in CO_2 and CH_4 emissions from reducing the use of the least-efficient coal power stations in the 4-for-2 °C Scenario occurs in the United States. Following a US Supreme Court ruling in 2007 that classified greenhouse gases as pollutants, the US Environmental Protection Agency (EPA) determined that climate change endangers public health and welfare, and that CO_2 and other greenhouse gases contribute to this endangerment. This finding established the authority of the US EPA to regulate CO_2 emissions (including from power plants) under the Clean Air Act. The US EPA proposed a carbon pollution standard for new power plants in March 2012, which, if adopted, would effectively prevent the construction of new coal power plants without carbon capture and storage (CCS). Additionally, the US EPA has the authority to propose performance standards for existing fossil fuel-fired power plants, which are responsible for about 33% of total energy-related CO_2 emissions in the United States, though there are no official plans to do so currently and would likely only follow the finalisation of standards for new power plants. The Clean Air Act appears to allow the US EPA considerable flexibility in applying standards to existing sources, such as allowing facilities that emit less than the standard to generate credits that can be sold to higher-emitting facilities. While any such standard is likely to face significant opposition from some electric power producers, its application would open the way to realising the reductions envisaged in the 4-for-2 °C Scenario and help natural gas, despite increasing prices towards 2020, to maintain the market position that it gained in the power sector in 2012, relative to coal, as a result of low gas prices.

India sees the third-largest reduction in emissions from coal-fired power generation as a result of the assumed coal power plant restrictions in the 4-for-2 °C Scenario. Despite the recent construction of more efficient coal capacity under the Ultra Mega Power Projects (UMPP) policy, India still has one of the lowest average conversion efficiencies in coal-fired power generation in the world, estimated at just 28%, or eleven percentage points below the global average. This is linked to the average age of the coal-fired power plant fleet and the relatively poor quality of domestic coal, which has an ash content of up to 60%. While increased coal washing at mining complexes is a possibility (which would also help alleviate transportation bottlenecks by reducing the amount of coal transported), plant managers are often reluctant to attempt to change coal quality due to concerns about operational problems.

The low average conversion efficiency of coal in India is exacerbating local concerns that air pollution is increasingly causing health problems and having adverse economic effects. A recent study estimated the extent of health effects at 80 000 to 115 000 premature deaths in 2011/2012, at an economic cost of $3.3-4.6 billion (Goenka and Guttikunda, 2013). India currently does not have strict standards for pollutants from power plants, except for particulate matter, and is suffering from peak shortages which make it difficult to impose additional constraints on power plant operation and dispatch. A new National Mission on Clean Coal Technologies is under discussion, whose task would be to foster work on integrated gasification combined-cycle and advanced ultra supercritical technologies, as well as CCS. With air pollution concerns growing, interest in clean coal technologies and minimum conversion standards might increase, with spin-off benefits for the climate: in the 4-for-2 °C Scenario in India, SO_2 emissions from the use of coal in power generation are 14% lower than in the New Policies Scenario by 2020, NO_x emissions are 8% lower and $PM_{2.5}$ emissions are 3% lower.

Emissions savings in the European Union due to the reduced use of the least-efficient coal power plants are the fourth-largest globally by 2020 in the 4-for-2 °C Scenario. There are several measures readily available with which to implement this policy. They include, particularly, the EU Emissions Trading System (ETS), although the level of CO_2 prices under the EU ETS is currently too low to incentivise a shift away from the least-efficient coal power plants, particularly given the current low price of coal relative to natural gas. Measures would be needed to ensure a level of CO_2 prices sufficient to facilitate the switch. The Large Combustion Plants Directive, established in 2001, limits operating hours of thermal power plants that exceed specified emissions levels for SO_2, NO_x and dust, is another tool that could be used to implement the policy. Demand-side measures tempering electricity demand growth, as included in the Energy Efficiency Directive, can support the reduced use of the least-efficient coal plants.

Reducing methane releases to the atmosphere in upstream oil and gas operations

Energy-related methane emissions stem from the production, transportation, distribution and use of all fossil fuels and from biomass combustion. We estimate that such emissions currently amount to 125 Mt CH_4 per year. Using the standard 100-years GWP of 25 from the Intergovernmental Panel on Climate Change (IPCC), this amounts to 3.1 Gt CO_2-eq.[14] It should be stressed however that there is a shortage of hard, measured, data on methane

14. Considering shorter time periods than 100 years, the CO_2-equivalent emissions are even larger, given that the 20-years GWP of the IPCC is 72, which increases the need to address CH_4 emissions in the short term. See also Alvarez, *et al.* (2012) for a discussion of the choice of GWP.

emissions; estimates rely primarily on multiplying "emissions factors" for various activities by "activity levels"; the emissions factors themselves can be traced to studies made by the Gas Research Institute and US EPA in the United States (US EPA, 2013).

In the oil and gas industry, methane emissions occur across the entire value chain.[15] Transmission and distribution of natural gas releases considerable amounts of methane into the atmosphere due to leakage or venting (which may be voluntary or involuntary), particularly in countries with a large and ageing distribution network, such as Russia and the United States. Additional methane emissions occur during incomplete combustion, both in end-use and in flaring. The extent of emissions in transmission, distribution and end-use is poorly known, as many of these emissions result from unintended leaks in ageing infrastructure. Addressing such leakage is a challenging and potentially costly task, beyond the short-term focus considered here. The larger potential for reducing methane emissions from oil and gas in the short term lies in optimising operational practices upstream, where the sources of emissions are relatively well-known. Technologies to reduce them are available (in large part through the work of the US EPA Gas Star Program) and the necessary action can be implemented through the existing sophisticated industry, dominated by large companies with strong technical skills and budgets. We estimate that the global oil and gas upstream industry released 45 Mt of CH_4 emissions (1 115 Mt CO_2-eq) to the atmosphere in 2010 (Spotlight).

Both venting and flaring give rise to methane emissions during oil and gas field operations. Venting (as defined here) includes both the intentional release of methane to the atmosphere (as part of normal operations) and "fugitive emissions", which are unintended – the results of leaks, incidents, or ageing or poorly maintained equipment. Some emissions from venting can be reduced at comparatively low cost by applying operational best practices, such as increased inspection and repairs, minimising emissions during completion operations and workovers[16], and reducing the frequency of start-ups and blow-downs. Equipment can also be converted, or designed, to reduce emissions: low-cost options include modifying dehydrators and converting gas-driven pumps and gas pneumatic device controls to mechanical controls. Additional but more capital-intensive potential lies, for example, in replacing leaking compressors with new ones and installing vapour recovery units on tanks. Production of unconventional gas has been particularly criticised because of the large amount of methane that can be released to the atmosphere during the flowback phase after hydraulic fracturing. Controlling such emissions is part of the IEA "Golden Rules" for unconventional gas development, and such rules are being adopted in a growing number of countries, for example in the US EPA's New Source Performance Standards for the oil and gas industry in the United States (IEA, 2012c).

15. Research efforts are underway, including at the University of Texas at Austin and the Environmental Defense Fund, to study methane emissions at each process step of the oil and gas value chain.

16. Workover is the term used for maintenance operations requiring interventions inside an oil or gas well, requiring temporary interruption of production. Depending on the sequence of operations, small volumes of gas may be released to the atmosphere.

SPOTLIGHT

How large are methane emissions from upstream oil and gas?

Though data on methane emissions are generally poor, it is estimated that about 550 Mt of methane emissions in total are released into the atmosphere every year (IPCC, 2007), of which around 350 Mt come from anthropogenic sources. In the *WEO Special Report: Golden Rules for a Golden Age of Gas*, we estimated total energy-related methane emissions to be 125 Mt, of which 90 Mt come from the oil and gas supply and distribution (IEA, 2012c). The US EPA has recently published a comparable global assessment of 129 Mt, with the contribution of oil and gas supply and distribution at 80 Mt in 2010 (US EPA, 2012a). Much more work is needed fully to understand the magnitude of methane emissions in the absence of widespread detailed measurements.

There is no global database available that distinguishes methane emissions from upstream oil and gas field operations from those that occur during the processing, transmission and distribution of gas. For the purpose of this *Special Report*, we therefore conducted a detailed assessment of methane emissions from oil and gas field operations. During oil field operations, methane emissions occur either from incomplete combustion in flaring (where associated gas cannot be brought to the market due to the remoteness of the oil fields and a lack of infrastructure, such as in Russia, the Middle East, Africa and the Caspian Region) or as a result of leakage during associated gas handling processes and (predominantly) venting at hydrocarbon storage tanks, compressors or pneumatic devices. During field operations dedicated to natural gas production, CH_4 emissions occur mostly from venting during normal operations of drilling and well completion, and unloading (including flowback after hydraulic fracturing), but also from condensate tanks, pneumatic devices, compressors and dehydrators.

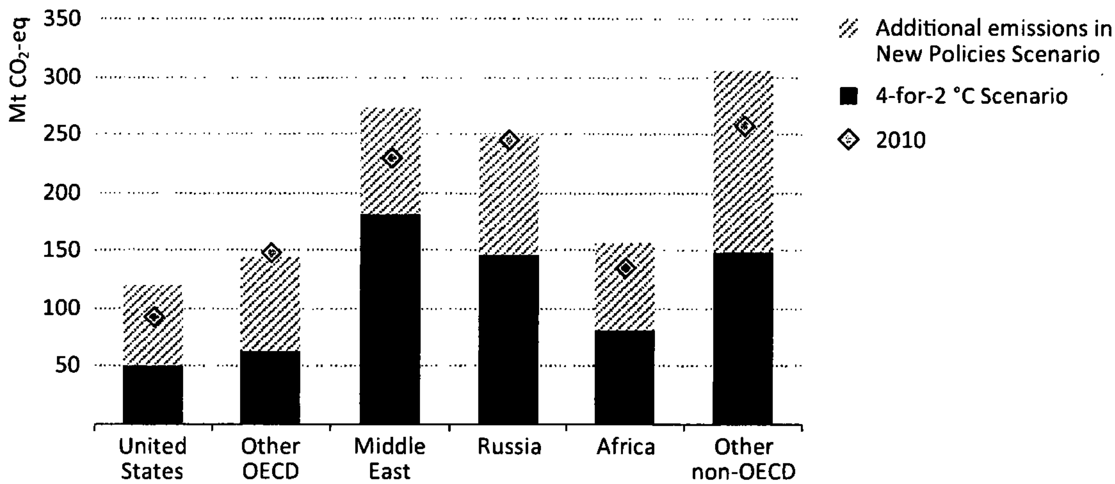
For the analysis of the volume of gas flared during oil field operations, we used the satellite data made available through the Global Gas Flaring Reduction Partnership of the World Bank to estimate the amount of methane which might remain unburned, based on an assessment of regional practices. For the analysis of methane emissions from venting during other oil and gas field operations, we used a detailed bottom-up analysis by the US EPA that assessed US methane emissions by process step and equipment type as a basis for our global assessment (US EPA, 2013). Using this analysis as a starting point, together with production levels by region, we analysed country-specific field operation practices according to the type of development (unconventional/conventional and onshore/offshore), by region and by type of hydrocarbon, taking into account the average age of existing oil and gas fields, the regulatory environment and the availability of technology. This enabled us to derive a global assessment of total methane emissions from oil and gas field operations, which are assessed as 45 Mt CH_4 (1 115 Mt CO_2-eq) in 2010. Of this, 17 Mt CH_4 comes from gas fields and 27 Mt CH_4 from oil field operations. Of the latter, 3.2 Mt are released as a consequence of incomplete combustion during gas flaring. Unsurprisingly, the largest emitters are the regions with high oil and gas production levels, *i.e.* Russia (10 Mt) followed by the Middle East (9 Mt) and Africa (5 Mt).

Gas that becomes available in relatively large quantities as a by-product of oil production (associated gas) often has no commercially viable outlet. It will not normally be vented, for safety reasons, but will be flared. Gas flaring converts methane into CO_2, *i.e.* still a greenhouse gas, but with lower Global Warming Potential. Reducing flaring has been a long-standing goal of the international community – it would substantially reduce both CO_2 and methane emissions – but the large investment required cannot materialise quickly. On the other hand, combustion is not always fully complete, which means that unburned methane is inadvertently released to the atmosphere from an otherwise controlled process, the amount varying with the design of the flaring equipment, and other parameters, such as wind speed (US EPA, 2012b). To reduce flaring on a large scale, infrastructure and equipment, such as compressors and pipelines, need to be built to bring the gas to markets or to enable it to be used for local power generation a comparatively capital-intensive process. Less capital-intensive options, such as the optimisation of flaring equipment or gas re-injection, need to be promoted in the short term.

All the technologies to pursue short-term optimisation from upstream operations in order to reduce methane emissions from venting and flaring are readily available, which means that the pace of reduction can be significant if the right policies and enforcement procedures are adopted (Figure 2.10). In the 4-for-2 °C Scenario, such short-term policies, including reducing venting and improving flaring efficiency, reduce methane emissions from oil field operations by about 300 Mt CO_2-eq. in 2020 (or 40% of oil-supply related methane emissions), relative to the New Policies Scenario, in which no additional regulation to address venting and flaring is assumed beyond that in place today, such as those targeting "green" completion equipment in the US EPA's New Source Performance Standards for the oil and gas industry. For gas field operations, the decrease is 280 Mt CO_2-eq (or about 55% of gas supply-related methane releases). The largest reductions are in Russia, the Middle East, Africa and the United States. They are achieved through a combination of rapid and broad-based implementation of low-cost and technological best operational practices, *e.g.* fewer start-ups/shutdowns, more frequent inspections, installation of electronic flare ignition, replacement of pneumatic controls by mechanical ones and upgraded dehydrators. These measures would account for about half of the reduction in emissions in 2020. The remainder would be accounted for by the first results from reduction endeavours that are more complex, take more time to implement and require larger investments. This category includes modifications like the installation of pressurised storage tanks with vapour recovery units, replacing compressors by ones with higher emissions standards and capturing emissions from individual wells. The impact of these measures would be even larger beyond 2020, as methane emissions from the upstream are likely to continue to increase in line with increasing oil and gas production.

Regulations exist in many countries to reduce venting and flaring, for example, in Russia, Ukraine, Argentina and Colombia. But there is often a lack of means of enforcement, particularly for venting. While the extent to which gas is flared is visible, vents are invisible and effective enforcement demands installation of specific equipment (for example, infrared cameras) and carrying out specific measurements. These equipment or processes are often unavailable. Another essential ingredient for success is raising awareness. Operators themselves, in particular in dispersed operations, are often unaware of the extent of their emissions and lack appropriate detection and measurement equipment. In relation to the reduction of venting, at least, this points to an initial focus on large, concentrated operations. A number of related efforts are currently underway, including the Global Methane Initiative and the US Natural Gas STAR Program. Supplementary options include extending carbon tax or trading schemes to methane, and imposing mandatory requirements to implement appropriate methane emissions control technologies and adopt best practices.

Figure 2.10 ▷ Methane emissions from upstream oil and gas by scenario, 2020



Fossil-fuel subsidy phase-out

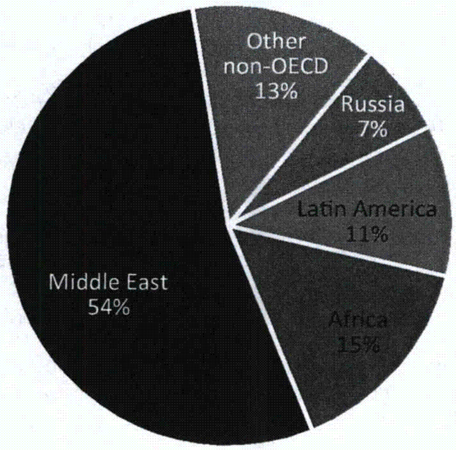
Estimates from the *WEO-2012* suggest that fossil-fuel consumption subsidies worldwide amounted to $523 billion in 2011, up almost 30% on 2010 and six times higher than the financial support given to renewables (IEA, 2012a).[17] Fossil-fuel subsidies were most prevalent in the Middle East, at around 40% of the global total. These estimates indicate the extent to which end-user prices are reduced below those that would prevail in an open and competitive market. Such subsidisation occurs when energy is imported at world prices and sold domestically at lower, regulated prices, or, in the case of countries that are net exporters of a product, where domestic energy is priced below international market levels.

In recognition that subsidy reform is likely to be a challenging and slow process in many countries because of political obstacles, the 4-for-2 °C Scenario does not encourage high expectations for a universal phase-out in the short term. A total phase-out by 2020 is assumed in fossil-fuel importing countries, as in the New Policies Scenario; but in exporting countries (where sustained reforms are likely to be more difficult), we assume a more gradual phase-out: relative to the New Policies Scenario, subsidisation rates are reduced

17. See IMF (2013) for additional discussion of subsidies.

by an additional 25% by 2020, before being completely removed by 2035.[18] As a result of these efforts, CO_2 emissions are reduced by 360 Mt in 2020, relative to the New Policies Scenario (Figure 2.11). Savings are greatest in the countries of the Middle East, which account for 54% of all savings, followed by Africa at 15%, and Latin America at 11%. Besides the cautious approach adopted towards subsidy reform in the 4-for-2 °C Scenario, the fact that these savings come on top of those already achieved in the New Policies Scenario explains the relatively low share of abatement resulting from fossil-fuel subsidy reform, compared with the effect of the other policies adopted in the 4-for-2 °C Scenario.

Figure 2.11 ▷ Change in world CO_2 emissions through fossil-fuel subsidy reform in the 4-for-2 °C Scenario relative to the New Policies Scenario, 2020



Subsidy reform is difficult as the short-term costs imposed on certain groups of society can be very burdensome and induce fierce political opposition. In Indonesia, for example, an attempt to increase gasoline and diesel prices by 33% in April 2012 induced strong public protests. Similarly, several weeks of nation-wide protests followed the complete removal of gasoline subsidies in Nigeria in January 2012. Concerns about inflation in several other countries in Asia and political and social unrest in parts of the Middle East and North Africa have delayed, and in some cases reversed, plans to reform energy pricing. Nonetheless, fossil-fuel subsidies represent a significant burden on many national budgets and political support for fossil-fuel subsidy reform has been building in recent years. In net-importing countries, in particular, efforts to reform have been closely linked to the unsustainable national financial burden created by the growth of subsidies as import prices rise. Even some net-exporting countries have taken steps to curtail the effect of artificially low domestic prices on export availability and foreign currency earnings (Table 2.2).

18. Subsidisation rate is calculated as the difference between the full cost of supply and the end-user price, expressed as a proportion of the full cost of supply.

Table 2.2 ▷ Recent developments in fossil-fuel consumption subsidy policies in selected countries

Country	Recent developments
Bolivia	In January 2012, the government returned to the issue of phasing out subsidies for gasoline and diesel, after efforts in 2011 failed in the face of strong opposition.
China	Implemented a tiered electricity pricing system in July 2012. Announced in March 2013 that prices of oil products would be adjusted every ten working days to better reflect changes in the global oil market.
Egypt	Announced in August 2012 a commitment to gradually phase out subsidies to energy-intensive industries. Plans to implement a "smart card" system to manage sales of subsidised gasoline and liquefied petroleum gas (LPG).
Ghana	Cut fuel subsidies in February 2013. As a result, prices of premium gasoline, diesel prices, kerosene, heavy fuel oil and LPG increased.
India	In January 2013, allowed state fuel retailers to start increasing the price of diesel on a monthly basis until it reaches market levels and raised the price cap on LPG cylinders. The 2013-2014 budget for petroleum product subsidies has been cut by more than 32%, compared to the previous year, from Rs 969 billion to Rs 650 billion (approximately $12 billion).
Indonesia	Announced policies to reduce subsidy expenditure in May 2012: tracking fuel use by vehicle; banning state-owned and (certain) company vehicles from using subsidised fuels; substituting natural gas for gasoline and diesel; and reducing electricity use in state-owned buildings and street lighting.
Iran	Significantly reduced energy subsidies in December 2010 as part of a five-year programme to gradually increase prices of oil products, natural gas and electricity to full cost prices. In January 2013, ended supplies of subsidised gasoline for cars with engines of 1 800 cubic centimetres and above, and restricted sales of subsidised gasoline near border areas.
Jordan	Raised the price of gasoline and electricity tariffs for selected industrial and services sub-sectors in June 2012. Since November 2012, subsidies have been removed from all fuels except LPG and global oil prices have been reflected via a monthly review.
Malaysia	In April 2012, announced that subsidies for gasoline, diesel and cooking gas would continue to be provided under the current administration.
Mexico	Gasoline and diesel prices are being raised slightly every month in 2013 to bring them closer to international levels.
Morocco	In June 2012, raised the price of gasoline by 20% and diesel by 10%.
Nigeria	A nation-wide strike followed a complete removal of gasoline subsidies in early January 2012, which doubled prices. Gasoline prices were then cut by a third, partially reinstituting the subsidy. Announced in March 2013 that there were no plans to reduce subsidies on premium gasoline.
Russia	Plans to increase regulated domestic natural gas tariffs by 15% for all users from July 2013.
Saudi Arabia	In May 2013, the Economy and Planning Minister indicated that subsidy rationalisation was something the country is seeking to address as they have become expensive and are causing damage to the economy.
South Africa	Energy regulator granted power utility Eskom an 8% per year average electricity price increase over the next five years, which will effectively reduce electricity subsidies.
Sudan	Commenced a subsidy reduction programme in June 2012, but in December 2012, announced that there were no plans to cut fuel subsidies further in 2013.
Thailand	In early 2013, announced that LPG prices would be increased monthly by 50 satang (approximately $0.02) monthly over the next year.

Because of the social sensitivity of the issue (and because every country must consider its specific circumstances), there is a raft of key principles to be adhered to when implementing such reforms. For example, inadequate information about existing subsidies is frequently an impediment. Before taking a decision about reform, governments must first precisely examine energy subsidies, including their beneficiaries, to identify low-income groups that depend on subsidies for access to basic energy services, and quantify their costs and benefits, in order to determine which subsidies are most wasteful or inefficient. Making more information available to the general public, particularly about the budgetary burden of subsidies, is a necessary step in building support for reform.

While the removal of fossil-fuel subsidies tends to improve long-term economic competitiveness and fiscal balances, it may, nonetheless, have negative economic consequences in the short term, particularly for certain groups, and any such reform must be carried out in a way that allows both energy and other industries time to adjust. Governments may well be wise to dissociate themselves from direct responsibility for price-setting, either by liberalising energy markets, or, at least, by establishing automatic mechanisms for price changes.

Box 2.3 ▹ Sustainable Energy for All and the 4-for-2 °C Scenario

Providing access to modern energy offers multiple economic and social benefits. Yet, today 1.3 billion people do not have access to electricity and 2.6 billion people rely on the traditional use of biomass for cooking (IEA, 2012a). These people mainly live in rural areas in developing Asia and sub-Saharan Africa. The United Nations Sustainable Energy for All (SE4All) initiative addresses this urgent problem, but investments under current and planned policies will not be enough to achieve universal energy access by 2030 (IEA, 2011a).

The SE4All initiative sets specific targets for reaching the goal of universal access to modern energy services by 2030, including reducing energy intensity at an average annual rate of 2.6% between 2010 and 2030, and increasing the share of renewables. The policy measures proposed in the 4-for-2 °C Scenario allow important steps to be taken towards these goals: in particular, the energy intensity target is more than reached as a result of the proposed policy package. The proposed ban on the least-efficient coal power plants helps to increase the share of renewables, but the level reached in 2030 is still short of the SE4All target.

Reducing methane emissions from upstream oil and gas is not part of the SE4All initiative, but it could also support the achievement of universal access in countries with considerable flaring. Nigeria, for example, had the third-largest population in the world without access to electricity in 2010, around 79 million people or half of the total population. The country already makes steps towards reducing flaring in oil and gas production, and full implementation of such measures as in the 4-for-2 °C Scenario could save natural gas at a level that, if supplied to the domestic market, would be sufficient to provide basic energy needs to the currently deprived.

Even a commitment to subsidy reform will not be sufficient in the absence of certain institutional and administrative capabilities, and even physical infrastructure. There must be institutions that are capable of accurate and timely collection of data about existing subsidies, their distribution and the need for offsetting selective relief accompanying reform. Governments ultimately have the responsibility for gathering this far-reaching information, but other organisations may have the technical expertise necessary to aid the effort.[19]

Implications for the global economy

The policy package suggested in the 4-for-2 °C Scenario does not affect global and regional growth of GDP to 2020. GDP grows globally at 4.1% per year between 2012 and 2020, representing annual average growth of 2.2% and 6.0% in OECD and non-OECD countries respectively.[20] This neutral impact on GDP results from the combined implementation of the four policies that are assumed to be adopted and from relative price adjustments across all commodities, goods and services. In the period post-2020, however, the adopted policy measures foster economic growth, as investments in the programme are increasingly outweighed by fuel bill savings and resources get allocated more efficiently across the entire economy.[21]

Energy prices in the 4-for-2 °C Scenario are lower than in the New Policies Scenario: oil prices increase to $116 per barrel in 2020, or $4/barrel lower than in the New Policies Scenario, before declining in 2035 to $109/barrel, which is $16/barrel lower than in the New Policies Scenario.[22] Natural gas prices are lower in importing regions such as Europe or Japan. OECD steam coal prices reach $100/tonne in 2035, $15/tonne lower than in the New Policies Scenario. The activity level of each sector in each country is boosted or reduced, depending on the specific policies to which they are exposed (Figure 2.12).

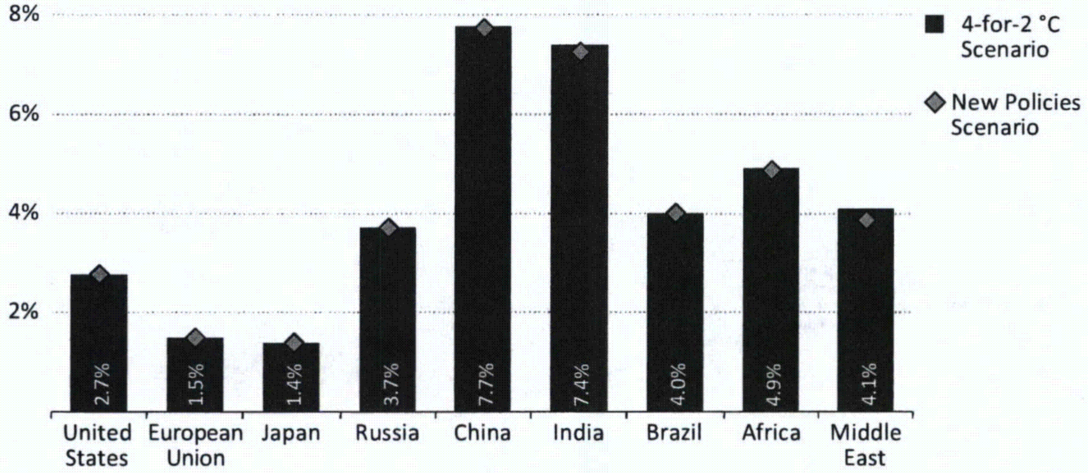
19. The *World Energy Outlook 2013* – to be released on 12 November 2013 – will examine the extent of fossil-fuel subsidies globally.

20. Slight deviations from New Policies Scenario GDP levels lie within the margin of error of standard mid-term economic forecasting, particularly in times of high uncertainty on projected economic activity (OECD, 2012; IMF, 2012).

21. Some of the proposed policy measures, such as energy efficiency, can foster economic growth even before-2020. See IEA (2012a) for a discussion of economic benefits of energy efficiency policy.

22. Each policy pillar may impact energy prices. For example, the multilateral and progressive phase out of fossil-fuel subsidies tends to push international fossil-fuel prices down, but domestic end-user prices increase in countries conducting the reform. Targeted energy efficiency measures also put a downward pressure on international prices by lowering energy demand. In contrast, minimising upstream methane emissions and reducing power generation from inefficient coal-fired power plants tend to increase production costs, thus leading to higher end-user prices of oil, natural gas and electricity.

Figure 2.12 ▷ **Average annual GDP growth by scenario in selected countries, 2012-2020**

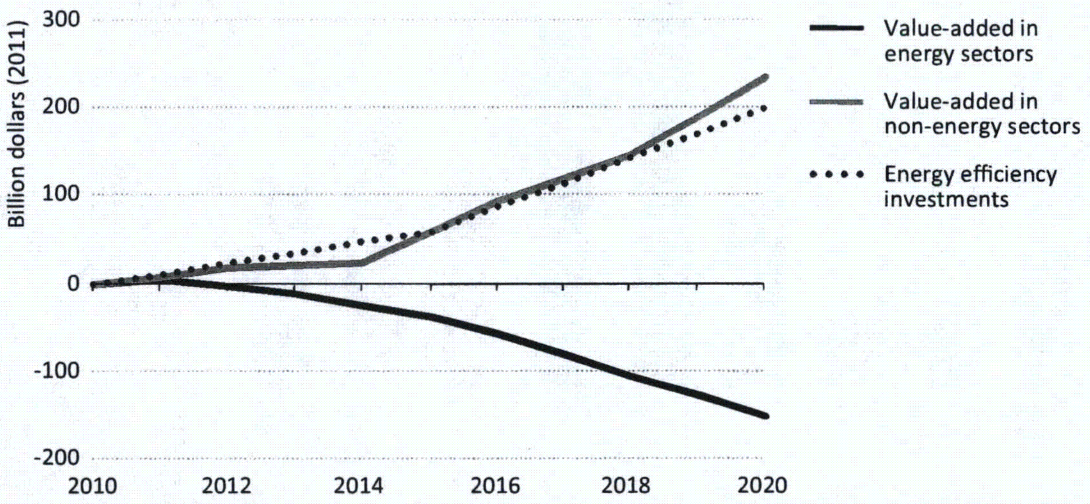


The value of economic activity in energy sub-sectors (comprising fossil-fuel extraction and processing, transport fuel production and shipping, and power generation) is slightly reduced, as they bear extra costs due to the reduction in methane emissions in upstream oil and gas operations and lower use of subcritical coal-fired power plants. By 2020, the global reduction in activity in the energy sector, measured by real value-added, reaches about $150 billion, a 3.7% decline relative to the New Policies Scenario. By contrast, other sectors of the economy benefit from lower energy prices and, in some cases, from additional investments linked to the adoption of more energy-efficient technologies that bring about savings in fuel costs. These variations in sectoral activity level offset each other, resulting in overall GDP-neutrality.

Energy efficiency measures adopted in the 4-for-2 °C Scenario bring about a $900 billion increase, relative to the New Policies Scenario, in cumulative investment from 2012 to 2020 (Figure 2.13). More than half of the increase is due to households purchasing more efficient energy consuming equipment (IEA, 2012a). The increase in cumulative investment in the service and transport sectors respectively reaches more than $160 billion and $170 billion. Energy intensive industries are responsible for only a small share of total energy efficiency investments, as their potential for energy savings is comparatively limited in the period to 2020. The reduction of methane emissions from upstream oil and gas requires a cumulative investment of around $20 billion up to 2020, while power generation investment is slightly reduced, relative to the New Policies Scenario, due to lower electricity demand, driven by energy efficiency policies.[23]

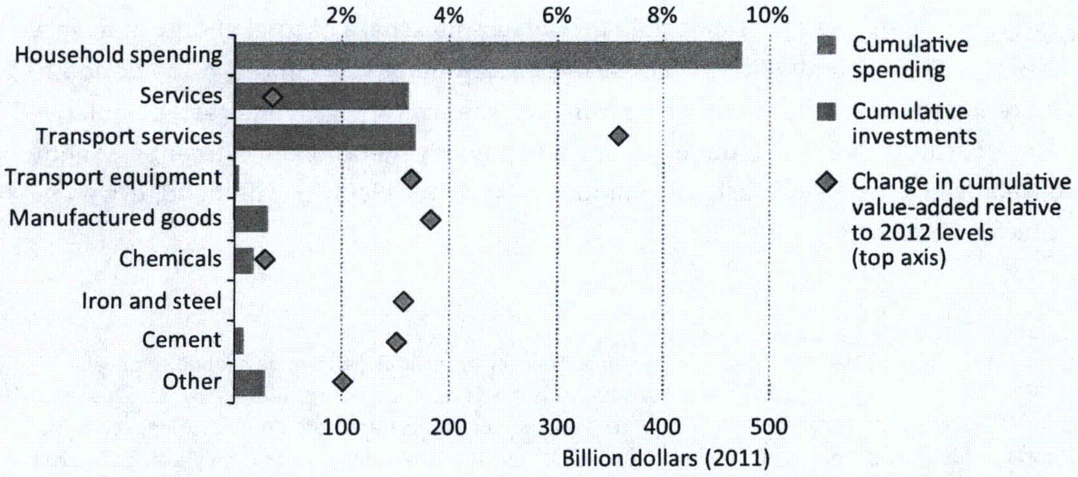
23. The implementation of the four policies will require transfer of technology from developed to developing countries. One such mechanism, Joint Crediting Mechanism (JCM), is being established by the Japanese Government. Through this mechanism a host country receives technology and sets up measuring, reporting, and verification of a project's emissions reductions. Projects include renewable energy, highly efficient power generation, home electronics, etc., which facilitates low-carbon growth in developing countries.

Figure 2.13 ▷ **World energy efficiency investment and change in energy and non-energy value-added in the 4-for-2 °C Scenario relative to the New Policies Scenario**



Capital-intensive sectors, facing sizeable fuel spending, benefit the most from the policies that are assumed to be adopted in the 4-for-2 °C Scenario (Figure 2.14). Transport services (including freight and shipping of other goods) are directly stimulated by targeted energy efficiency investments. Cumulative value-added to 2020 increases by 7%, relative to current levels, and 0.7% relative to the New Policies Scenario. Despite limited investments in energy efficiency, energy-intensive industries are particularly sensitive to the reduced energy prices stemming from the full policy package. This enables those industries to redirect spending to other primary factors, *e.g.* capital and labour, which translates into an increase in activity of around 1-3% through to 2020 (Chateau and Magné, 2013).

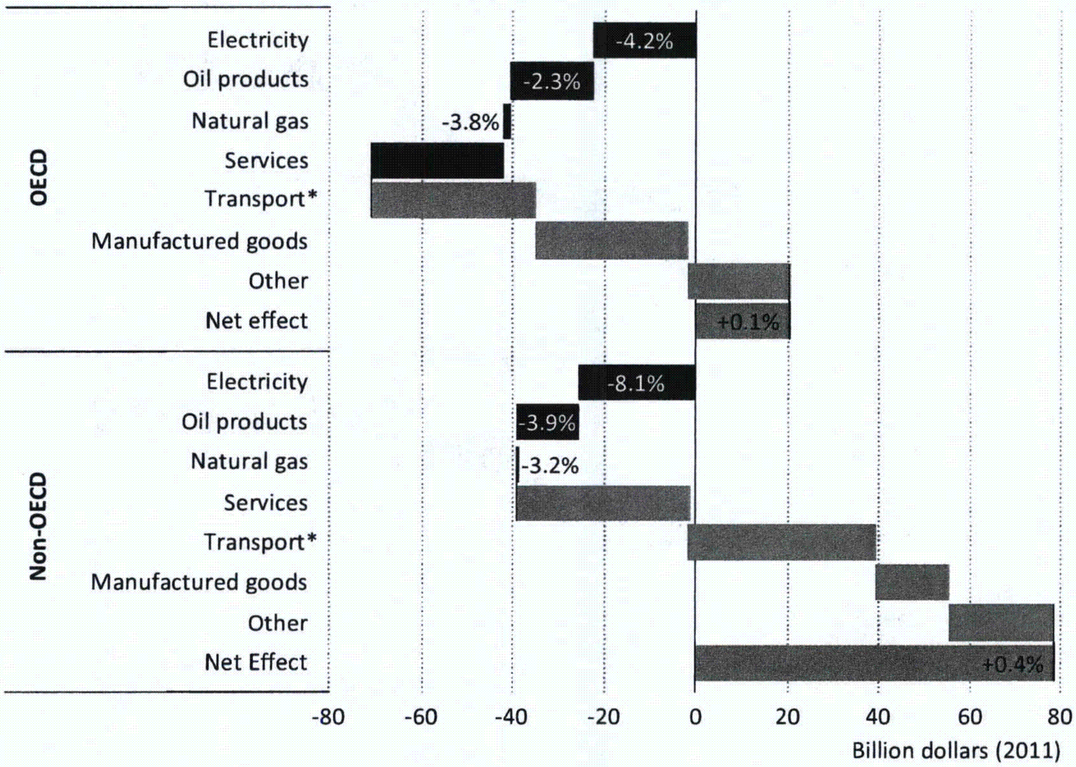
Figure 2.14 ▷ **Change in household spending, investment in energy efficiency and in sectoral value-added in the 4-for-2 °C Scenario relative to the New Policies Scenario, 2012-2020**



The manufacturing sector also sees reduced production costs and a 4% increase in cumulative activity. In relative terms, the policy impact for the services sector is limited. Given the sheer size of services in the global economy – currently around 60% of total value-added – the amount of capital invested in energy efficiency relative to capital in place is only a few percentage points. In addition, energy use is in the services sector is too limited to benefit significantly from reduced energy prices in the 4-for-2 °C Scenario.

The overall objective of reducing CO_2 and methane emissions entails sectoral and regional reallocations of supply and demand across all commodities, goods and services. Energy efficiency investments by households and firms reduce their energy bills, freeing up finance for the purchase of other goods. Prices of non-energy goods and services are moderated, as energy costs are lower. This stimulates an increase in activity in non-energy sectors that more than compensates for the reductions in the energy sector. The global trade impacts of the policies remain very limited – a mere 0.1% increase in 2020.

Figure 2.15 ▷ Impact on consumption of goods and services in households in the 4-for-2 °C relative to the New Policies Scenario, 2020

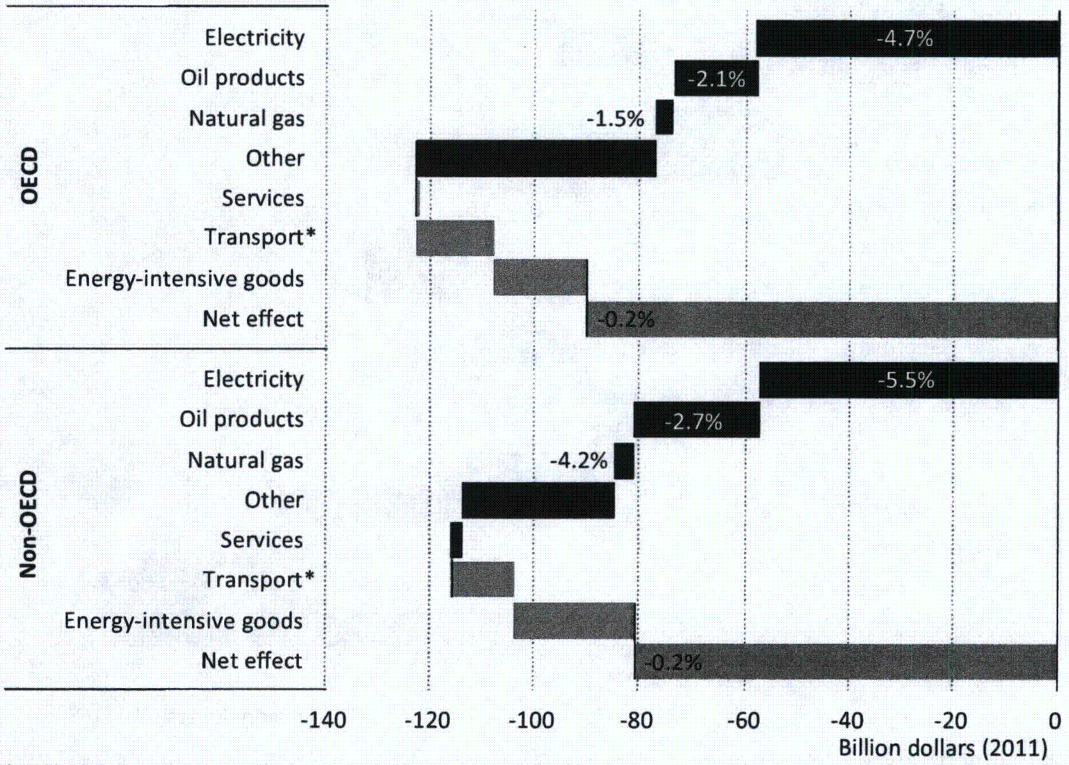


* Includes transport equipment and transport services.

The reshuffling of sectoral activity is chiefly triggered by the altered consumption behaviour of households, a distinct driver of economic growth, particularly in OECD countries (Figure 2.15). Goods and services with relatively low energy content or whose adoption may bring about significant energy savings, such as in transport through the deployment of energy-efficient vehicles, are specifically targeted by the policy package implemented in OECD countries. In 2020, the four policies in OECD countries lead to an increase in household expenses of above 1% for transport services and equipment, and also for manufactured products relative to the New Policies Scenario.[24] Both categories of additional expense are of similar magnitude, around $35 billion.

Energy expenses in OECD countries are between 2% and 4% lower than in the New Policies Scenario, equivalent to a net reduction of about $40 billion. The net increase in OECD household consumption is limited to 0.1%. Similar net deviations are observed in non-OECD countries, though non-OECD economies are generally more industry-oriented and energy spending accounts generally for a larger share in consumption. Energy efficiency measures redirect consumption towards goods and services which embed less energy. Therefore, the set of policies in the 4-for-2 °C Scenario induces a more significant boost in household consumption. The services sector is further developed, as economic development proceeds in these countries. In 2020, household spending on energy goods is cut by almost 4% in the case of oil products. The electricity bill diminishes by more than 8%, incentivised by the reform of fossil-fuel subsidies.

Figure 2.16 ▷ Impact on consumption of goods and services in firms in the 4-for-2 °C relative to the New Policies Scenario, 2020



* Includes transport equipment and transport services.

The overall increase in household consumption is, to some extent, counterbalanced by an overall reduction in consumption of goods and services by firms (Figure 2.16). Energy expenses by firms are reduced in similar proportion to those of households. But demand

24. Welfare impacts of the 4-for-2 °C Scenario are qualitatively similar to consumption trends illustrated in this section.

by firms for other goods, notably manufactured products, is maintained, though changed in detail. The resulting net impact on consumption by firms is a 0.2% decrease ($90 billion) in OECD countries, offsetting the net increase in households. Larger cuts in the energy bills of non-OECD firms also lead to a net 0.2% drop in consumption in 2020 (-$80 billion).

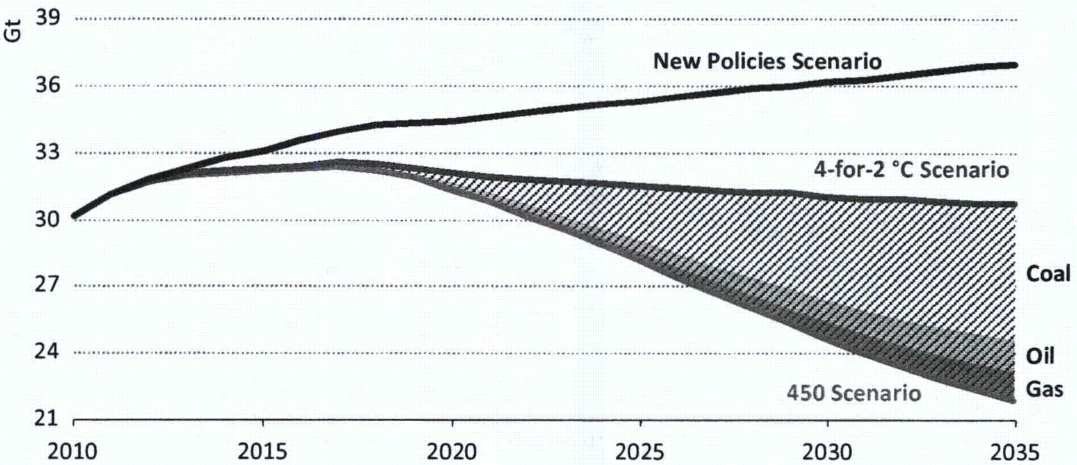
The assumed multilateral reform of fossil-fuel consumption subsidies leads to more efficient resource allocation across the entire economy and is thus welfare-enhancing in countries implementing the reform. This measure benefits Middle Eastern countries particularly, which results, in combination with other elements of the policy package, in a slight increase in their GDP.

Building blocks for steeper abatement post-2020

The long-term implications of the 4-for-2 °C Scenario

The implementation of assumed policy measures in the 4-for-2 °C Scenario significantly reduces growth in global CO_2 emissions from the energy sector. Global energy-related CO_2 emissions continue to grow in the short term, to 32.1 Gt in 2020,[25] but this is only some 2% higher than is required to put the world on track for a global temperature rise in the long term no higher than 2 °C. Emissions stabilise after 2020 and start falling slowly, reaching 30.8 Gt in 2035, 6.2 Gt (or 17%) lower than in the New Policies Scenario (Figure 2.17). Almost 60% of the CO_2 savings in 2035 occur due to the reduced use of coal as a result of lower electricity demand and less use of the least-efficient coal power plants. The use of oil is also reduced, contributing 25% to overall emissions reductions, largely due to efficiency standards in road transport and the phase-out of fossil-fuel subsidies. Natural gas contributes another 17% to emissions reductions, due to lower electricity demand and the phase-out of fossil-fuel subsidies. However, the use of natural gas, still grows until 2035 in the 4-for-2 °C Scenario, though at a reduced average annual rate, relative to 2010, of 1.1%. It is the only fossil fuel for which demand still increases significantly over today's levels.

Figure 2.17 ▷ **World energy-related CO_2 emissions by scenario**



25. Including CH_4, energy-related emissions reach 34.9 Gt CO_2-eq in 2020.

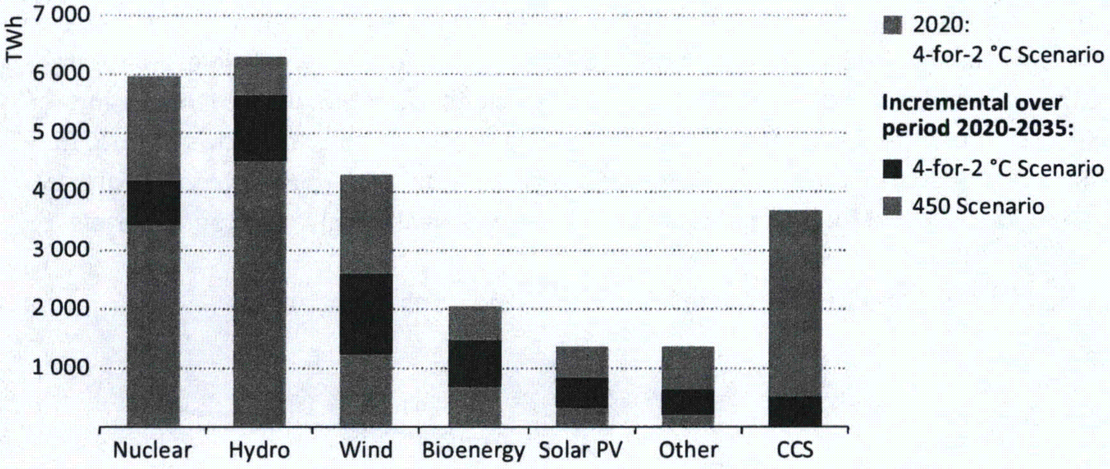
These additional measures are not sufficient alone, however, to reach the 2 °C target in the long term, as CO_2 emissions are 8.8 Gt (or 40%) higher than the required level in 2035, a level which, if realised, would represent only a 13% probability of stabilisation at 2 °C, and a 50% likelihood of reaching 2.9 °C. In order to change course post-2020 and put the world firmly on track consistent with a for a 50% chance of reaching the 2 °C target, further reductions are required. Relative to the 4-for-2 °C Scenario, these additional reductions amount to a cumulative 78 Gt through 2035.

Technology options for ambitious abatement post-2020

The relevance of low-carbon technologies

For the required transformation of the energy sector post-2020 to achieve climate targets, all technology options will be needed and their early availability is essential to minimise the additional costs associated with their deployment. While deep emissions reductions are possible if consumers were to reduce demand for energy services such as mobility or comfort, such changes are considered unlikely and might entail lower economic activity. The acceptable keys to the required emissions reduction are, therefore, technological developments and ongoing improvements in efficiency.

Figure 2.18 ▷ World electricity generation from low-carbon technologies by scenario



Note: Other includes geothermal, concentrated solar power and marine.

In the power sector, for example, a profound change in the way electricity is generated is needed post-2020. In the 4-for-2 °C Scenario, the share of low-carbon technologies including renewables, nuclear and CCS, reaches 40% in 2020, up from 32% today, but this is still well short of the required level of almost 80% in 2035, as reflected in the 450 Scenario (see Chapter 1). Achieving this target will require the use of all low-carbon technologies, with the largest contribution coming from increased use of renewables, as electricity output from hydro, wind, biomass, solar and other renewables combined in 2035 is over 4 000 terawatt-hours (TWh) (or almost 40%) higher than in the 4-for-2 °C Scenario (Figure 2.18). Electricity generation from nuclear power needs to increase by almost 1 800 TWh in 2035 (or about 40%) over the level achieved in the 4-for-2 °C Scenario. In relative terms, the largest scale-up, post-2020, is needed for CCS, at seven times the level achieved in the 4-for-2 °C Scenario, or around 3 100 TWh in 2035, with installation in industrial facilities capturing close to 1.0 Gt CO_2 in 2035. Projects in operation today in all sectors capture only 6 Mt CO_2, implying a very rapid deployment of CCS in many applications. For all low-carbon technologies, the removal after 2020 of market and non-market barriers towards their wider adoption will require a consistent policy effort over the next decade.

In the transport sector, a shift towards low-carbon fuels is required as improving the efficiency of road vehicles alone will not lead to the steep reductions required after 2020 (IEA, 2012b). While natural gas and biofuels are promising alternatives to oil, their potential to reduce emissions relative to oil is limited, either due to their carbon content (natural gas) or questions with regard to their sustainability and conflicts with other uses for the feedstock (biofuels). From today's perspective, high expectations fall on the deployment of electric and plug-in hybrid vehicles, with their share of all PLDV sales required to rise by above one-quarter by 2035 (as in the 450 Scenario). Such a dramatic shift away from current sales patterns is unprecedented in global car markets. In order to attain such a steep increase in market shares, electric vehicles need to be freely available to the mass market at competitive costs by 2020, solutions having been identified to address issues such as driving range (for example, fast recharging infrastructure) or other issues crucial to consumer acceptability.

The relevance of carbon capture and storage

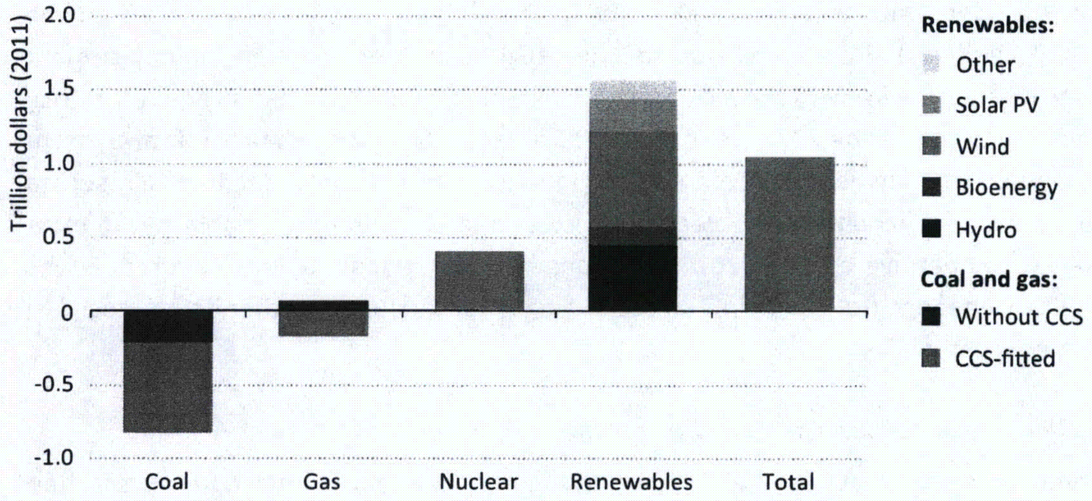
The large deployment of CCS after 2020 is required partly as a fossil-fuel assets protection strategy.[26] In 2020, there are almost 2 000 GW of coal-fired capacity and almost 1 800 GW of gas-fired capacity installed worldwide in the 4-for-2 °C Scenario, together representing 58% of total electricity generation. Deploying CCS and retrofitting fossil-fuel plants with CCS avoids the need to mothball large parts of this fleet and improves the economic feasibility of the climate objective, in particular in regions where geological formations allow for CO_2 storage (IPCC, 2005). So far, only a handful of large-scale CCS projects in natural gas processing are operating, together with some low-cost opportunities in industrial applications. While many projects are economically viable because CO_2 is purchased for enhanced oil recovery (EOR), there is no single commercial CCS application to date in the power sector or in energy-intensive industries. Additional to technological and economic challenges, CCS must overcome legal challenges related to liabilities associated with the perceived possibility of the escape of the CO_2 gases that are stored underground. Existing policies so far are insufficient to incentivise investments in commercial-scale CCS (Box 2.4). Although progress has been made towards improving the regulatory framework, sufficient

26. See Chapter 3 for an analysis of the economic implications of stronger climate policies.

technology and deployment support is lacking and the absence of a substantial price signal has impeded necessary development of CCS technology.

Past analysis has demonstrated that emissions mitigation becomes more costly without CCS (IEA, 2011c).[27] In the power sector, delaying introduction of CCS from 2020 to 2030 would increase the investment required to keep the world on track for the 2 °C target by more than $1 trillion, as the need for additional investment in other low-carbon technologies, such as renewables and nuclear, would more than offset the reduced investment in coal power plants and CCS (Figure 2.19). Although a reduction of electricity demand can accommodate lower CCS deployment in the power sector, there are limits to the extent to which energy efficiency can reduce energy demand without reducing energy services.

Figure 2.19 ▷ Change in cumulative investment in power generation if CCS is delayed, relative to the 450 Scenario, 2012-2035



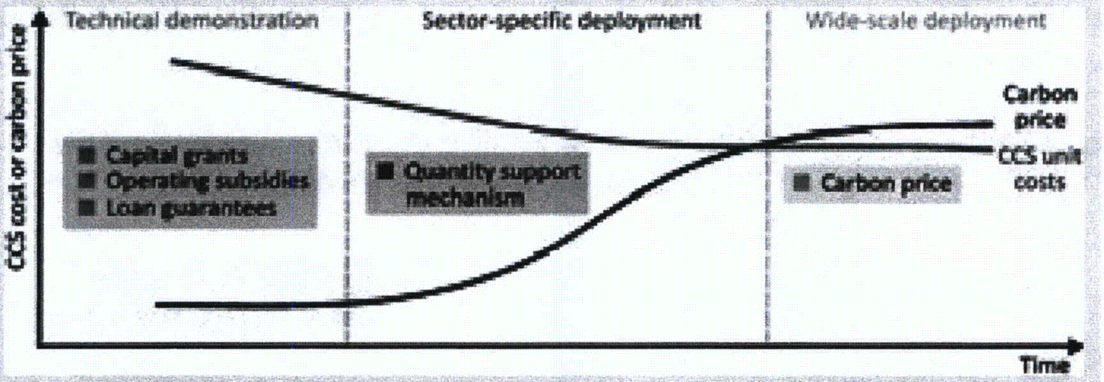
While the delayed availability of CCS can be compensated in the power sector by increasing investment in renewables and nuclear, albeit at higher costs, the fact that alternatives are not available to compensate for a shortfall of the deployment of CCS technologies in industry is a bigger challenge. Energy-efficient equipment can go a long way (and is deployed to its maximum in the 450 Scenario), but the potential for renewables in industrial applications is limited. A higher use of decarbonised electricity in industry has some potential, for example in iron and steel via secondary steelmaking, but this would not allow the production of certain product qualities. Without the deployment of CCS or an alternative low-carbon technological breakthrough in industrial processes, industry would struggle to reach the levels of decarbonisation necessary to achieve the 450 Scenario, so putting further pressure and imposing greater costs on sectors with more options to decarbonise, such as transport and power generation.

27. The analysis of the cost of delaying CCS in this section is based on a comparison of the cost of reaching the 450 Scenario from *WEO-2012* with those of the Delayed CCS Case that was presented in *WEO-2011* and that assumes that CCS is introduced in 2030, *i.e.* ten years later than in the 450 Scenario.

Box 2.4 ▷ Policies to support CCS

CCS deployment requires strong policy action, as present market conditions are insufficient and current CO_2 pricing mechanisms have failed to provide adequate incentives to drive it. Governments need to put in place incentive policies that support not only demonstration projects but also wider deployment. The optimal portfolio of incentive policies needs to evolve as the technology develops from being relatively untested at a large scale to being well-established. The incentive policy portfolio should initially be weighted towards technology-specific support, explicitly targeting the development of CCS into a commercial activity through the provision of capital grants, investment tax credits, credit guarantees and/or insurance (Figure 2.20). At the early stage, measures are needed to enable projects to move ahead in order to generate replicable knowledge and experience. Targeted sector-specific industrial strategies are then needed to move CCS from the pilot project phase to demonstration and then deployment phases. In the long term, a technology-neutral form of support, *e.g.* in the form of a CO_2 price, allows the deployment of CCS to be considered in relation to other cost-effective abatement options.

Figure 2.20 ▷ Policy framework for the development of CCS



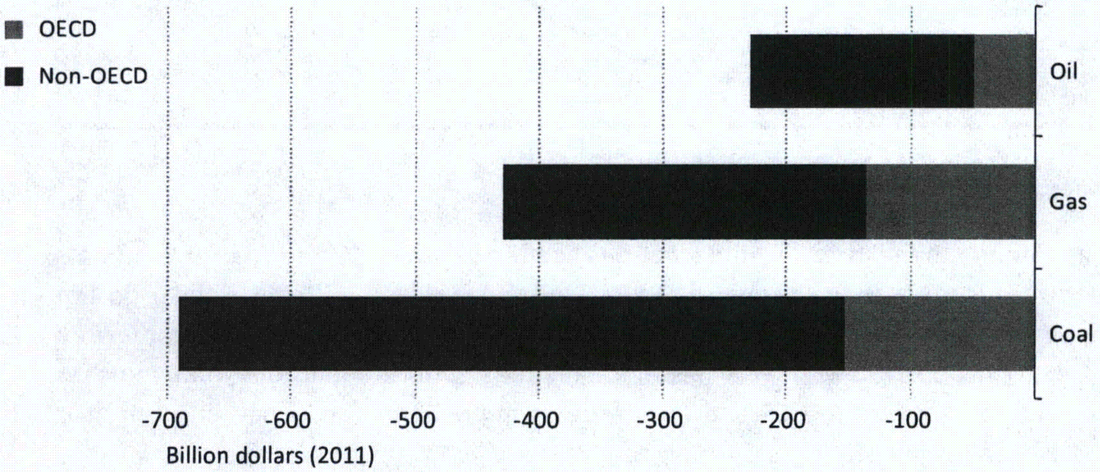
Source: Adapted from IEA (2012d).

In addition to the tailored incentive policies needed to drive CCS forward, governments need to ensure that the terms of regulatory frameworks (or their absence) do not impede demonstration and deployment of CCS. In this context, a regulatory framework is the collection of laws (and rules or regulations, where applicable) that removes unnecessary barriers to CCS and facilitates its implementation, while ensuring it is undertaken in a way that is safe and effective. Jurisdictions in the European Union, the United States, Canada and Australia have established legal and regulatory frameworks for CCS over the past few years (IEA, 2011c). While developing a legal and regulatory framework for a novel technology is a daunting challenge, a regulatory framework can, within limits, be developed in phases, with regulations tailored to the stage of technology deployment, as has been done in some jurisdictions, so long as the regulatory process stays sufficiently ahead of the game. But, in any case, framework development must begin as soon as possible to ensure that a lack of appropriate regulation does not slow deployment.

CCS can not only safeguard otherwise stranded assets in power generation and industry, but also has a value for fossil-fuel producers. To achieve climate targets, CCS would mainly be applied to coal- and gas-fired power plants and in the iron and steel, and cement industries, which largely consume coal. If the introduction of CCS in power generation and industry is significantly delayed, coal consumption must decrease correspondingly if climate targets were to be met: while coal consumption would decline from around 5 200 million tonnes of coal equivalent (Mtce) today to 3 300 Mtce in 2035 if CCS was introduced on a large scale by 2020, it would be reduced by another 900 Mtce if the introduction of CCS was delayed by ten years.

Oil and gas producers would also be affected by delayed introduction of CCS. Although gas consumption would still increase over today's level, growth would be slower without the application of CCS to gas-fired power plants. For oil producers, the effect of delaying CCS would be indirect: in order to keep cumulative CO_2 emissions the same in the absence of CCS, the transport sector would need to compensate by reducing emissions further through wider deployment of electric vehicles. This could reduce oil consumption by around 1.3 million barrels per day in 2035, compared with introduction of CCS by 2020. Overall, if the introduction of CCS was delayed until 2030, then coal producing countries would lose revenues of \$690 billion, gas producers would lose \$430 billion and oil producers about \$230 billion (Figure 2.21). The combined loss of revenue for oil and gas producers is roughly equal to that of coal producers.

Figure 2.21 ▷ Change in fossil fuel cumulative gross revenues by type and region if CCS is delayed, relative to the 450 Scenario



Policy frameworks post-2020

The role of carbon prices

The analysis in this chapter has shown that it is possible in 2020 to be within reach of a 2 °C trajectory through the adoption in the short term of a number of well-targeted, decisive policy interventions that will not damage economic growth. After 2020, the energy transition must move from being incremental to transformational, *i.e.* an energy sector revolution, is required, which will be attained only by very strong policy action. The pivotal challenge is to move the abatement of climate policy to the very core of economic systems, influencing in particular, all investment decisions in energy supply, demand and use. Every feasible abatement opportunity will need to be seized. An important way to achieve this is by pricing carbon emissions.

By reflecting in energy prices the hidden cost of climate damage, well-judged carbon pricing gives all producers and consumers the necessary incentive to reduce greenhouse-gas emissions, while allowing flexibility in the technical and business solutions adopted to make these reductions. Carbon pricing provides an incentive for innovation, and depending on the policy design, could help the fiscal position of governments.

Carbon pricing can be implemented in a multitude of ways, matching national circumstances and climate objectives. Carbon taxes provide simplicity and investment certainty, while emissions trading can be used if flexibility and international linkages are a higher priority. The revenues raised can be used to maximise overall economic welfare (for example, by reducing other distortionary taxes) and, in this case, the net benefit can exceed the economic slow-down resulting from energy price rises (Parry and Williams, 2011). The revenues raised can also be used in a targeted way to offset the impact of increasing prices for low-income consumers or vulnerable industries and, if designed well, can still maintain the appropriate incentives for cleaner energy choices. Targets in an emissions trading scheme can be based on an absolute emissions cap, which gives certainty over the abatement outcome, or an emissions intensity, which provides greater flexibility for rapidly-developing economies and can have a lesser impact on energy prices.

A key advantage of carbon pricing is its potential to optimise action internationally, either through international credit mechanisms or the linking of domestic emissions trading schemes. International linking allows abatement to occur first where it is cheapest, driving investment flows and technology to regions with abatement opportunities. In theory, this should appeal both to buying and selling nations – buyers benefit from cheaper compliance with emissions targets and sellers profit from higher unit sales. However, other political considerations mean that, in the real world, linking decisions is complex. There may be concerns about outflows of capital from buying countries, and "loss" of cheap abatement options in selling countries. There may also be concern that international linking will raise domestic carbon prices in regions with ample abatement opportunities, flowing through to energy prices. Even if technical design elements enable linking, these political considerations may mean that carbon pricing policies remain mostly domestic or regional for some time.

Given the important role that carbon pricing must play from 2020, it is essential to use the few years ahead to design and test carbon pricing systems in order to gain experience. Experience in the EU ETS and other systems, such as the US-based Regional Greenhouse Gas Initiative, has shown that it can take a number of years to put a carbon pricing system in place, and several more to settle on robust and sustainable policy parameters (see Chapter 1). Countries that have worked through these design issues and have carbon pricing as an available tool will be at a distinct advantage in managing the ambitious emissions reductions that will be required under any new international agreement consistent with keeping the long-term average global temperature rise to below 2 °C.

Box 2.5 ▷ Clean energy standards

Emissions trading does not necessarily mean a "cap and trade" system: there are many design options for integrating a flexible carbon price into investment decision-making. For example, a clean energy standard (CES) for the electricity sector could work in a very similar way to an intensity-based ETS, embedding a clear incentive for a clean energy transition across electricity sector decision-making and retaining many of the benefits of carbon pricing. Under a CES, permits are awarded for each unit of clean electricity generated, on the basis (approximately) of avoided emissions compared to a baseline, which requires careful definition. Electricity suppliers must surrender permits corresponding to a required share of clean energy. The tradability of permits creates a price for a unit of low-carbon electricity generation, rather than a price for emissions. As with any emissions trading or crediting system, setting the emissions cap (in this case the required share of clean energy) at an ambitious level is critical to ensure that there is a functioning market that results in real, additional emissions reduction.

CES systems do not necessarily raise energy prices by as much as an equivalent cap and trade system because the cost passed through to consumers is only that of the required investment in clean energy, rather than a charge on all fossil-fuel generation. Conversely, they do not raise revenue for governments to use in an economically beneficial way and do not provide a clear signal for demand reduction.

Despite its importance, carbon pricing alone will not be sufficient to drive necessary changes. Direct targeted policies will be needed to unlock the energy efficiency potential, such as those proposed in the 4-for-2 °C Scenario to 2020. Energy efficiency is often blocked by non-market barriers which, left in place, could distort the response to carbon prices. The development of new technologies also requires targeted support, both to bring down costs and to allow for scaling-up to the level required for the long term. Typical examples are CCS, some renewable energy technologies, smart grids and electric vehicles (which also require supporting infrastructure). It may also be necessary directly to discourage investment in long-lived energy infrastructure that might otherwise be beyond the reach of a carbon price signal. Although some sectors are less responsive to a carbon price, such a market signal may still play a supporting role. For example, fuel-economy standards in transport are much more effective if complemented by fuel-excise charges to prevent rebound, as is provided for in the 450 Scenario.

Managing climate risks to the energy sector

Building resilience now

Highlights

- The energy sector must ensure that its assets are resilient to the physical impacts of the climate change that is already occurring and in prospect, and also that its corporate strategy is resilient to the possibility of stronger climate change policies being adopted in the future. If these implications of climate change are not factored into investment decisions, carbon-intensive assets could need either to be retired before the end of their economic lifetime, idled or undergo retrofitting.
- The energy sector is not immune from the physical impacts of climate change and must adapt. In mapping energy system vulnerabilities, we identify some impacts that are sudden and destructive, with extreme weather events posing risks to power plants and grids, oil and gas installations, wind farms and other infrastructure. Other impacts are more gradual, such as sea level rise on coastal infrastructure, shifting weather patterns on hydropower and water scarcity on power plants. Urban areas, home to more than half the world's population, experience annual maximum temperatures that increase much faster than the global average. Our analysis, which takes account of the changing climate, shows that global energy demand for residential cooling is 16% higher in 2050 than when this effect is not factored in. Developing countries' cooling needs increase the most, particularly in China.
- Even under a 2 °C trajectory, upstream oil and gas generates gross revenues of $107 trillion through to 2035. Though 15% lower than they might otherwise be, these revenues are nearly three times higher than in the last two decades. Stronger climate policies do not cause any currently producing oil and gas fields to shut down early. Some fields yet to start production are not developed before 2035, but this risk of stranded assets affects only 5% of proven oil reserves and 6% of gas reserves. Lower coal demand impacts on coal supply but, as investment costs are a small share of overall mining costs, the value of stranded assets is relatively low.
- In the power sector overall, gross revenues are $57 trillion through to 2035 under a 2 °C trajectory, 2% higher than those expected on the trajectory now being followed, as higher electricity prices outweigh lower demand. Net revenues from existing nuclear and renewables capacity are boosted by $1.8 trillion collectively, offsetting a similar decline from coal plants. Of the power plants that are retired early, idled or retrofitted with CCS, only 8% (165 GW) fail to fully recover their investment costs.
- Delaying stronger climate action until 2020 would avoid $1.5 trillion in low-carbon investments up to that point, but an additional $5 trillion would then need to be invested through to 2035 to get back on track. Developing countries have the most to gain from investing early in low-carbon infrastructure in order to reduce the risk of needing to prematurely retire or retrofit carbon-intensive assets later on.

Introduction

As the largest source of greenhouse-gas emissions, a significant burden lies with the energy sector to deliver the 2 degrees Celsius (°C) climate goal committed to by governments. Chapter 2 examined the need and the potential for policy makers to take short-term climate actions while negotiating long-term deals. This chapter shifts focus to the need and scope for self-interested action by the energy sector. The global climate agreement that is expected to come into force in 2020 is both within the lifetime of many energy assets operating today and within the current planning horizons of the industry: it is, accordingly, one of the present uncertainties that the industry has to manage as it continues to invest. Many of the investment decisions being taken today do not appear to be either consistent with a 2 °C climate goal or sufficiently resilient to the increased physical risks that are expected to result from future climate change. Is the energy sector beginning to factor these issues into its planning and investment decisions, or is there a risk that it will need to write-off some of its assets before the end of their economic life and before they have generated the financial returns expected of them?

Climate change is, and will continue to be, an important issue for the energy sector. The industry can rise to the challenges brought about by climate change, but this will require the reorientation of a system valued at trillions of dollars and expected to receive trillions more in new investment over the coming decades. This chapter analyses some key issues that the energy sector must confront. It begins by examining the range of physical impacts that the changing climate might have on our energy system, highlighting those parts of our energy infrastructure that may be most vulnerable and need to become more "climate resilient". It then analyses the potential economic impact on the energy sector of the stronger climate policies, necessary to meet the 2 °C climate goal, which may be adopted, measuring this in terms of the impact on the sector's future revenues, and on the lifetime and profitability of existing assets (in terms of fossil-fuel reserves and energy infrastructure) and those yet to be discovered, developed or built. After all, in a world where confidence in the conclusions of climate science is hardening and the available carbon budget is shrinking, those companies deriving their revenues most closely from fossil fuels are at the highest risk from changes in energy and climate policies, potentially undermining the business models that have historically served them well. The chapter also looks more broadly at the implications if stronger actions on climate change were delayed, considering the simple question of whether it is better to act now or act later.

Impacts of climate change on the energy sector

The energy sector is not immune to the impacts of climate change and here we examine the exposure of different parts of the energy system to the associated physical risks. Even stringent action to contain the extent of climate change, such as realisation of the 2 °C climate goal, will not eliminate the impacts of climate change and the need to adapt to it (Box 3.1). Without such adaptation, climate change will increase the physical risks to energy supply, pushing up capital and maintenance costs, impairing energy supply reliability and accelerating the deterioration (and therefore the pace of depreciation) of assets. The industry must judge the extent to which it will be impacted by future climate change and how it will need to adapt to the new physical risks, whether, for example, through changes in the location and the resilience of new infrastructure, through the decentralisation of the energy network, or by insuring against loss. Given the national importance of some energy infrastructure, government will also have an important role to play. Overall, developing an effective strategy will involve the interplay between a broad range of stakeholders, including governments, energy companies, climate scientists and insurers.

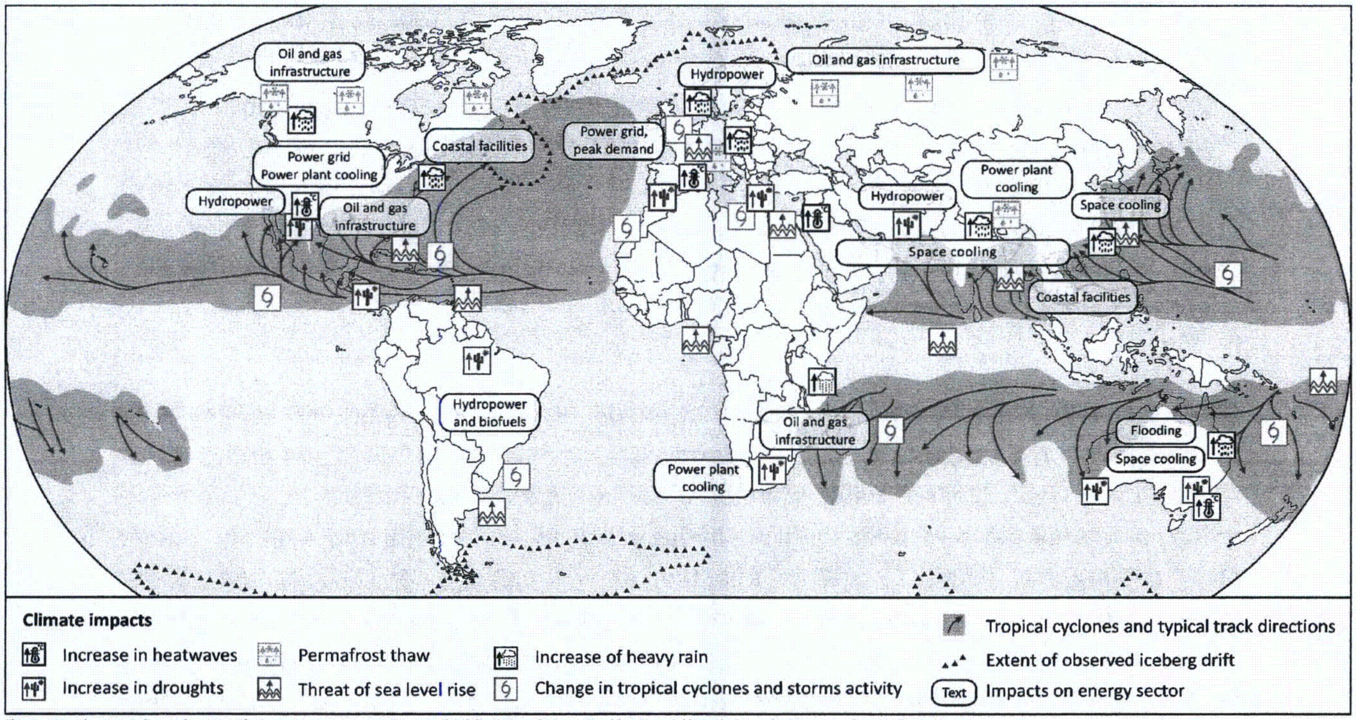
3

Box 3.1 ▷ Climate change adaptation

While climate change **mitigation** describes actions to reduce greenhouse-gas emissions in the atmosphere, climate change **adaptation** relates to adjustments that are made in response to actual or expected climate events (or their effects), which either moderate the harm caused or exploit beneficial opportunities (UNFCCC, 2013). Significant efforts to mitigate climate change can reduce the need for adaptation, but not dismiss it entirely because of the global warming that will result from the accumulation of past long-lived greenhouse-gas emissions. Climate mitigation and adaptation are therefore not mutually exclusive strategies and there are synergies that can be exploited to enhance their cost-effectiveness.

Climate change impacts, and the adaptation needs, will vary by region and sector. Some of the impacts will be gradual, as a long-term increase in global temperature brings about a rise in sea level, greater water scarcity in some regions and changes in precipitation patterns. Energy demand patterns will change (such as for heating and cooling), power plant cooling and efficiency will be affected, as will hydropower output, and coastal infrastructure (including refineries, liquefied natural gas [LNG] plants and power plants) will be threatened (Figure 3.1). For example, in the United States alone nearly 300 energy facilities are located within 1.2 metres of high tide (Strauss and Ziemlinski, 2012). Other impacts of climate change are likely to be more sudden and destructive, with extreme weather events, such as tropical cyclones, heat waves and floods, expected to increase in intensity and frequency (Box 3.2). Cyclones can damage electricity grids and threaten or severely disrupt offshore oil and gas platforms, wind farms and coastal refineries. Heat waves and cold spells will impact upon peak load energy demand, putting greater stress on grid infrastructure and undermining the ability of power plants to operate at optimum efficiency. Gradual and sudden climate impacts can also interact, such as a sea level rise and more powerful storms combining to increase storm surges. Furthermore, disruptions to the energy system caused by climate events can have significant knock-on effects on other critical services, such as communications, transport and health.

Figure 3.1 ▷ Selected climate change impacts on the energy sector



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Sources: Based on ©Munich RE (2011), with information from Acclimatise (2009), Foster and Brayshaw (2013), Schaeffer, *et al.* (2012) and IEA analysis.

Box 3.2 ▷ Extreme weather – a new factor in energy sector decisions?

Climate change affects the frequency, intensity and duration of many extreme weather events and evidence shows that this is already happening (IPCC, 2007; Peterson, Stott and Herring, 2012). A recent report finds that the distribution of seasonal mean temperature anomalies has shifted toward higher temperatures and that the range of anomalies has increased, with an important change being the emergence of a category of extremely hot summertime outliers, relative to a 1951 to 1980 base period (Hansen, Sato and Ruedy, 2012). It also finds that, in the 1960s, less than 1% of the global land area (around the size of Iran) was affected by summertime extremes[1], but observations now point to this figure having increased to 10% (an area larger than India and China combined). A separate study links the 35-year warming trend in ocean surface temperature to more intense and larger tropical cyclones (Trenberth and Fasullo, 2008). In 2012, Tropical Storm Irene made landfall much further north than was typical and Hurricane Sandy was the largest hurricane ever observed in the Atlantic (NOAA National Weather Service, 2012). The 2003 heat wave in Europe is estimated to have caused up to 70 000 deaths (Robine, *et al.*, 2008) and, while the summer average was only 2.3 °C above the long-term average in Europe, August temperatures in several cities were up to 10 °C higher than normal. Several densely populated urban areas are already at high risk from natural hazards. For example, Tokyo and New York are at risk from cyclones and floods, while New Delhi and Mexico City are at risk from floods (UNPD, 2012).

The IPCC (2012) concluded that it is virtually certain that an increase in the frequency and magnitude of warm daily temperature extremes will occur over the course of this century. In a world where the average global temperature increases by 4 °C, relative to pre-industrial levels, several studies find that the most marked warming will be over land and actually be between 4 °C and 10 °C. A global temperature increase of 4 °C means that a 1-in-20 year extreme temperature event today is likely to become a 1-in-2 year event and, around the 2040's, about every second European summer could be as warm (or warmer) than the extreme summer of 2003 (Stott, Stone and Allen, 2004).

Energy demand impacts

Comprehensive global studies covering the impact of climate change on the energy sector are still lacking, though some regional and sector-specific analysis exists. The buildings sector has been examined in more depth than most, with studies finding that temperature increases are expected to boost demand for air conditioning, while fuel consumption for space heating will be reduced. The effects in the transport sector (such as higher use of air conditioners) and in the industry sector (changed heating and air conditioning needs) are expected to be on a smaller scale (Wilbanks, *et al.*, 2007). In agriculture, a warmer climate is likely to increase demand for irrigation resulting in a higher energy demand for water pumps.

1. Defined as being more than three standard deviations warmer than the average temperature.

Residential heating and cooling

Around one-quarter of global final energy consumption is in the residential sector – nearly 2 100 Mtoe in 2010 – with space heating accounting for around 30% of this and space cooling making up around 3%. At present, countries in cold climates, such as Canada and Russia, have high heating demand (heating degree days [HDD] of 4 000 or above), but a comparably low demand for space cooling (cooling degree days [CDD] below 300).[2] Countries in hot climates, such as India, Indonesia and those in Africa, have virtually no demand for space heating, but high cooling needs (CDD above 3 000). Other regions are situated in a more temperate climate or extend over different climate zones, such as the European Union and the Middle East where, for example, Iran has around 1 000 CDDs per year, while Saudi Arabia has more than 3 000 CDDs.

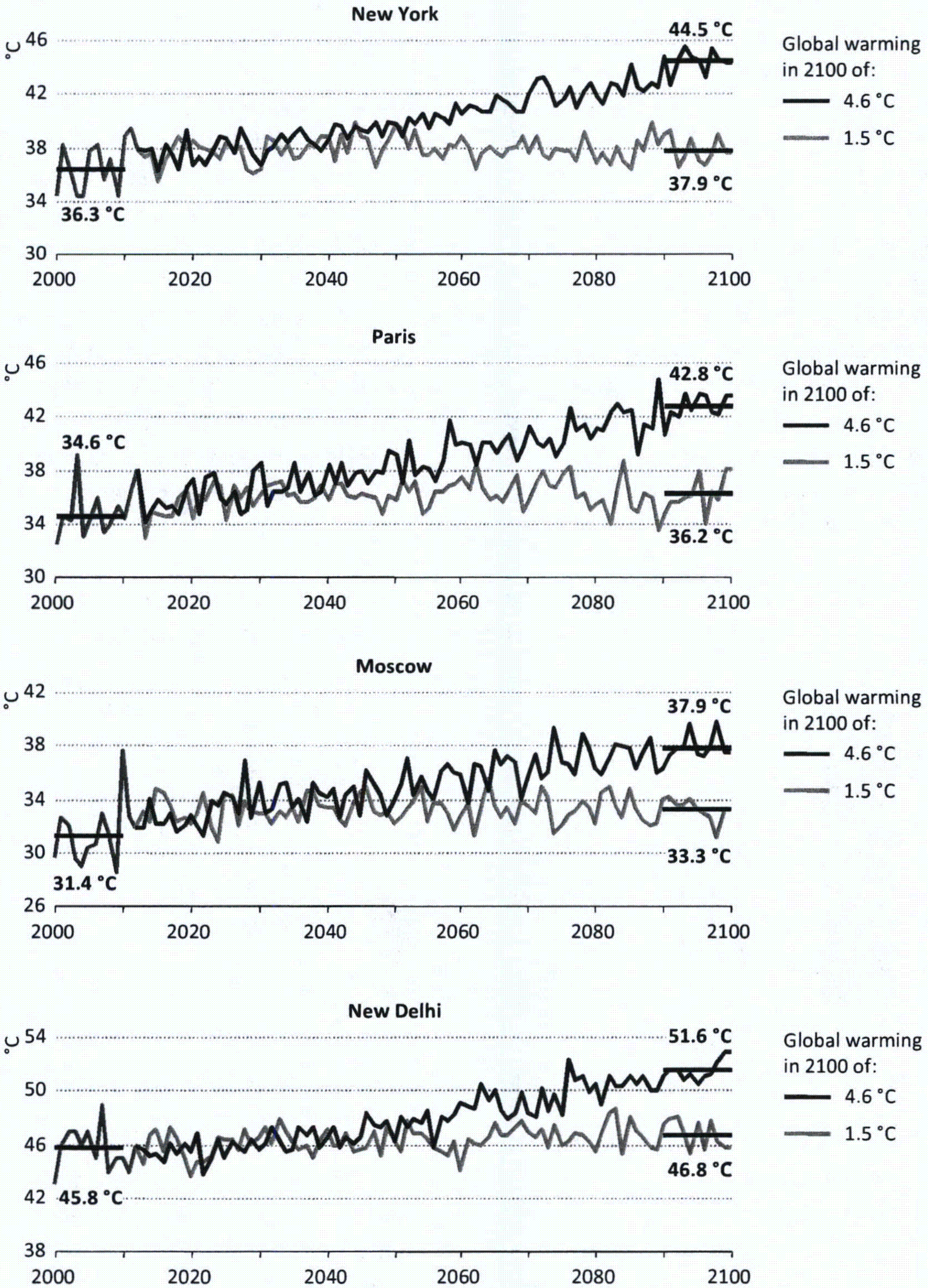
Urban areas, home to more than half the world's population, are at the forefront of the challenge of climate change. Annual maximum temperatures in cities increase much faster than the global average, fostered by the urban heat island effect. For example, an average global warming of 4.6 °C above pre-industrial levels by 2100 (as in the IPCC's RCP 8.5 Scenario) is projected to result in maximum summer temperatures in New York increasing by 8.2 °C (Figure 3.2) (Hempel, *et al.*, 2013). In such a case, the extreme summer experienced in Moscow in 2010 may be closer to the norm experienced in 2100, while the European summer of 2003 could be cooler than the average by that time. In a case where the average global warming is 1.5 °C above pre-industrial levels by 2100 (as in the IPCC's RCP 2.6 Scenario), the maximum summer temperature in New York is projected to increase by only 1.6 °C.

For this report, we have extended our World Energy Model to allow for the impact of climate change on the projections for heating and cooling energy demand in the residential sector.[3] Given the relatively long timescales over which climate impacts occur, the time horizon for this purpose is from 2010 to 2050, though it is recognised that the largest impacts will be felt after this date: our New Policies Scenario is consistent with an average global temperature increase of around 2 °C by 2050 (3 °C by 2100 and 3.6 °C by 2200), compared with pre-industrial levels. In addition to changes in average energy demand for heating and cooling, climate change may also increase peak-load demand for cooling.

2. HDD and CDD are measurements designed to reflect the demand for energy needed to heat or cool a building. HDD and CDD are defined relative to a base temperature – the outside temperature above/below which a building needs no heating or no cooling. For example, if 18 °C were the baseline temperature, a summer day with an average temperature of 25 °C would result in a CDD of 7.

3. The World Energy Model has been extended to 2050 for the climate impact analysis, where the effect on space cooling is based on the methodology proposed in McNeil and Letschert (2007). Demand for space heating is based on energy services demand, which is driven by factors including change in floor space per capita, price elasticity and a change in HDD. Data on population weighted degree days comes from the PLASIM-ENTS model (Holden, *et al.*, 2013).

Figure 3.2 ▷ Projected annual maximum temperatures in selected cities under different global warming trends

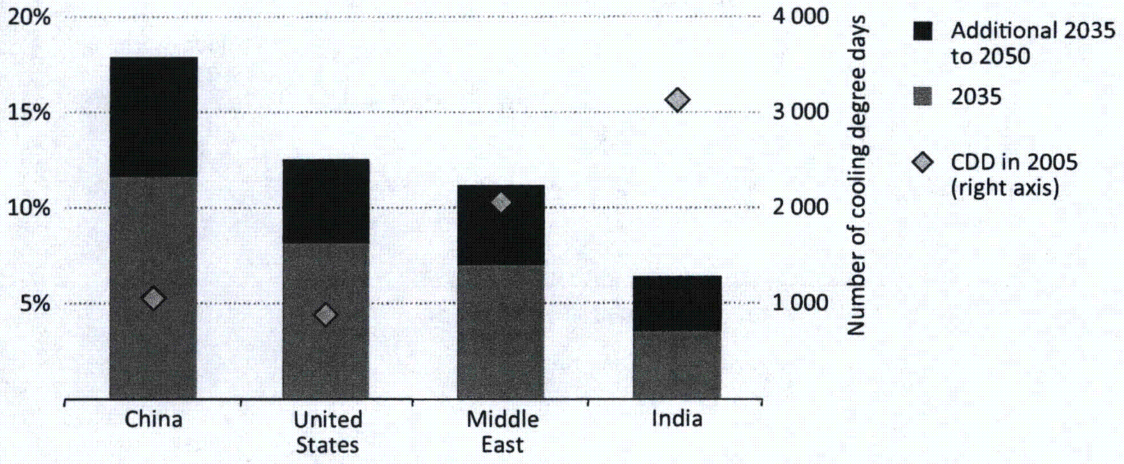


Note: The temperature trend is the average of five climate models.

Sources: NOAA (2013a); Hempel, *et al.* (2013); and IEA analysis.

Energy demand for cooling in the OECD was higher than in non-OECD countries in 2010. In our New Policies Scenario, not accounting for climate change, global energy demand for space cooling already grows by nearly 145% to 2035 and is around 175% higher by 2050, pushed largely by demand from emerging markets in Asia, primarily China. However, climate trends are going to change over the coming decades and, once these are taken into account, the results show that global energy demand for space cooling increases by around 170% to 2035 and 220% by 2050, compared with 2010 levels. In 2050, energy demand for cooling is significantly higher in non-OECD countries than in the OECD. In non-OECD countries demand increases by nearly 400% (105 million tonnes of oil equivalent [Mtoe]) compared to around 60% (20 Mtoe) in the OECD by 2050. The largest absolute change in energy demand for cooling is in China, where the effect of increasing incomes (boosting ownership of air conditioners) is complemented by increased cooling needs as a result of rising temperatures. In relative terms, the biggest change in cooling demand that occurs as a result of climate change (*i.e.* a comparison between our New Policies Scenario results with and without climate change) is in China, followed by the United States, the Middle East and India (Figure 3.3). All of the increase in energy demand for cooling in the residential sector is in the form of electricity, which can be challenging for power system stability during extreme heat waves.

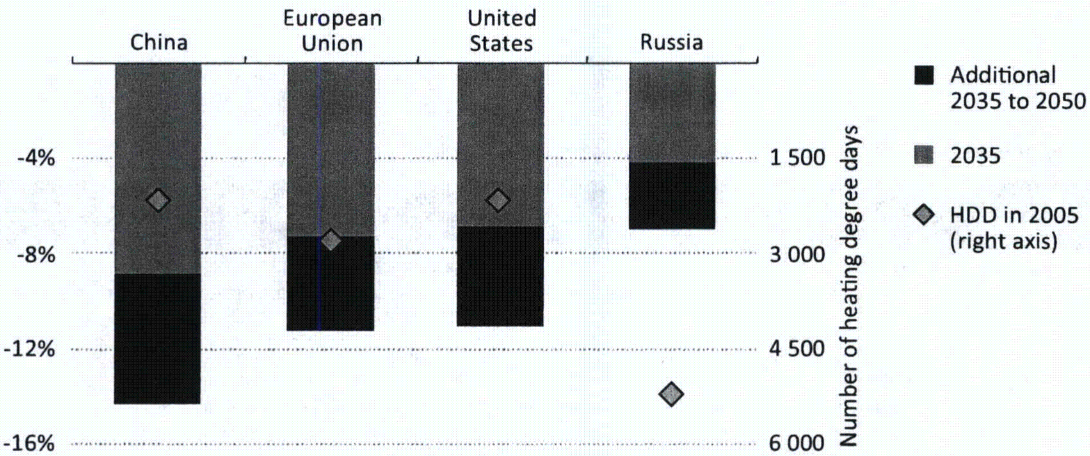
Figure 3.3 ▷ Change in energy demand for space cooling by region in the New Policies Scenario after accounting for climate change



Note: These regions cover almost three-quarters of the global energy consumption for space cooling.

In 2010, global energy demand for heating was ten times the level for cooling, with OECD countries accounting for around 60% of the total. In the case of energy demand for heating, a New Policies Scenario that does not take account of climate change projects a 20% increase to 2035 and 28% by 2050. Once climate change effects are taken into account, energy demand for space heating increases by only 11% to 2035 and 12% to 2050, compared with 2010 levels. In the OECD, energy demand for heating increases only marginally to 2035 and then declines to 2050, ending at a similar level (385 Mtoe) to 2010. Non-OECD countries drive almost all of the global increase, reaching around 260 Mtoe in 2050, with most of the increase occurring by 2035. Looking at the absolute change in energy demand before and after climate effects are taken into account, the largest reductions are in Europe, China and the United States. The largest relative reduction in space heating needs occurs in China (Figure 3.4). Less than 10% of global energy demand for heating is in the form of electricity, with the rest split among fuels, mainly gas.

Figure 3.4 ▷ Change in energy demand for space heating by region in the New Policies Scenario after accounting for climate change



Note: These regions cover almost three-quarters of global energy consumption for space heating.

Energy supply impacts

Fossil fuels

Oil and gas exploration and production already takes place in a number of challenging climates, and the industry has innovated over time to open up new frontiers, from deserts to deepwater to the Arctic Circle. Climate impacts on this sector will include those that are relatively gradual, such as a rising sea level and changing levels of water stress, and sudden impacts, including extreme wave heights, higher storm intensities and changing ice floes (Table 3.1). For example, ten Chinese provinces already suffer from water scarcity in per capita terms and, if this were to become more acute, existing coal operations (the coal sector has the largest share of industrial water use in China) and future plans to develop its huge shale gas resources could be affected (IEA, 2012a). Infrastructure will need to adapt to boost resilience to a changing climate, and this is likely to entail additional costs. Iraq, which also suffers from water scarcity, provides a current example of this, as it is investing around $10 billion to construct a Common Seawater Supply Facility that would treat 10-12 million barrels per day (mb/d) of seawater and transport it 100 kilometres to oil fields where it will help maintain reservoir pressure. This investment will mitigate future pressures on Iraq's valuable freshwater sources (see our *Iraq Energy Outlook* for more detail [IEA, 2012b]).

Table 3.1 ▷ **Selected climate impacts on the oil and gas sector by region**

Region	Share of world oil production, 2011*	Climate impact	Impact on the oil and gas sector
Middle East	33%	• Water stress • Increase in air and sea surface temperature	• Increase production costs • Reduce cooling capacity in certain processes, limiting the capacity of a given facility, *i.e.* LNG
OECD Americas	17%	• Increase in intensity of tropical cyclones (Gulf of Mexico) • Sea level rise • Water stress • Permafrost thaw (Alaska, north Canada)	• Increase costs of offshore platforms, *e.g.* increase platform height, and more frequent production interruptions • Increase the shut down time of coastal refineries • Reduce the availability of ice road transportation/increase pipeline maintenance
Russia	13%	• Permafrost thaw (Siberia)	• Reduce the availability of ice road transportation/increase pipeline maintenance
Africa	11%	• Water stress (North Africa) • Sea level rise (West Africa)	• Increase production costs • Increase the shut down time of coastal refineries
Latin America	9%	• Sea level rise • Increase in storm activity (Brazil)	• Increase the shut down time of coastal refineries • Increase in offshore platform costs
China	5%	• Increase in air and sea surface temperature (South China Sea) • Water stress	• Reduce cooling capacity in certain processes, limiting the capacity of a given facility • Render some unconventional production unfeasible or very costly (*i.e.* CTL)
OECD Europe	4%	• Increase in intensity of storms • Extreme wave heights (North Sea)	• Increase costs of offshore platforms and increase production interruptions
OECD Asia Oceania	1%	• Increase in intensity and frequency of tropical cyclones (Australia) • Increase in air temperature	• Increase costs of offshore platforms and increase production interruptions • Increase costs for cooling

*Note: Regional oil production includes crude oil, natural gas liquids and unconventional oil but excludes processing gains and biofuels supply.

Growing production of unconventional gas is expected to result in increased water demand for hydraulic fracturing, as highlighted in the *World Energy Outlook Special Report Golden Rules for a Golden Age of Gas* (IEA, 2012c). Shale gas or tight gas development can require anything between a few thousand and 20 000 cubic metres (between 1 million and 5 million gallons) per well. In areas of water scarcity, either now or due to climate change, the extraction of water for drilling and hydraulic fracturing may encounter serious constraints. The Tarim Basin in China holds some of the country's largest shale gas deposits, but is located in an area that suffers from severe water scarcity. In the United States, the industry is taking steps to minimise water use and increase recycling.

A major part – 45% of the remaining recoverable conventional oil resources (excluding light tight oil) – is located in offshore fields (1 200 billion barrels) and a quarter of these are in deep water (a depth in excess of 400 metres). Ice melt can have both positive and negative effects when looking at offshore oil and gas production. For example, the region north of the Arctic Circle is estimated to contain 90 billion barrels of undiscovered technically-recoverable crude oil resources, 47 trillion cubic metres of gas resources (more than a quarter of the global total) and 44 billion barrels of natural gas liquids (USGS, 2008). Longer ice-free summers in the Arctic are expected to result in longer drilling seasons (and new shipping routes), increasing the rate at which new fields can be developed in the future (though, in our projections, we do not expect a significant share of global oil and gas production to come from the Arctic offshore before 2035). On the other hand, the technical and environmental challenges are already significant and a number of projects have either been held back by the complexity of operations and by environmental concerns, or suspended due to escalating costs. More prolific ice floes and polar storms are likely to increase the risk of disruption during Arctic drilling, production and transportation (Harsem, Eide and Heen, 2011). Increased ice melt also reduces the availability of ice-based transportation (such as ice roads), adversely affecting oil and gas production at higher latitudes, such as in Alaska and Siberia. In the case of Alaska, the period that ice roads are open has halved since 1970 (NOAA, 2013b). Thawing permafrost can also shift pipelines and cause leaks, which will necessitate more robust (and expensive) design measures.

Extreme weather events can cause extensive damage that takes considerable time and money to repair. Employee evacuations and downtimes are increasing, as the design thresholds for offshore platforms are breached more frequently by extreme wave heights (Acclimatise, 2009). Offshore oil and gas rigs, such as those northwest of Australia and in the Gulf of Mexico, are already at risk from extreme weather events and the risks are expected to increase with climate change, with more severe events resulting in more production interruptions (IPCC, 2012). In 2005, Hurricane Katrina caused damage valued at $108 billion in the Gulf of Mexico, which included, together with Hurricane Rita, damage to 109 oil platforms and five drilling rigs (Knabb, Rhome and Brown, 2005). Large-scale midstream infrastructure, such as oil refineries and LNG facilities, is often located on the coast and sometimes in locations prone to extreme weather events and could be similarly exposed. In addition, refineries are large water consumers and may become more vulnerable to water stress, particularly in those countries where water is already a relatively scarce resource. LNG plants are typically either water-cooled or air-cooled and their efficiency is related directly to the temperature of the water or air available for cooling, a 1 °C temperature rise reducing efficiency by around 0.7%. A temperature rise in line with our New Policies Scenario could see LNG plant efficiency decline by 2%-3% on average, and more in hotter regions. Particular care needs to be taken over the implications of climate change for the location, design and maintenance regime for such long-life infrastructure, which is often regarded as being of strategic national importance.

In the case of coal production, which requires large amounts of water for coal mining activities (coal cutting, dust suppression and washing), increasing water stress may render certain operations more costly. An increase in the frequency and intensity of rainfall could cause flooding in coal mines and coal handling facilities. In addition, extreme weather can affect transport networks, disrupting the route to market, as observed when Queensland, Australia, was hit by tropical cyclones in 2011 and 2013.

Thermal power generation and electricity networks

We have shown the extent to which a warming climate may boost energy demand for cooling (mainly electricity). At the same time, rising air and water temperatures can have a direct impact on the efficiency of thermal power plants, either decreasing electricity output or increasing fuel consumption. High humidity also decreases the efficiency of thermal power plants equipped with cooling towers. Water stress, and an increase in water temperature, can have a profound impact on power generation. In China, water scarcity has meant that some power plants have turned to dry cooling systems, which cut water consumption sharply but also reduce plant efficiency. Water temperature not only impacts directly on power plant efficiency[4] but, in many countries, may also constrain operation because the temperature of cooling water discharged into rivers exceeds an authorised level. During the summer heat wave in 2003, for example, out of a total of 59 nuclear reactors in France, thirteen had to lower their output or shut down in order to comply with regulations on river temperatures leading to a total loss of 5.4 terawatt-hours (TWh) (EDF, 2013). Constraints due to these effects are expected to increase in the future (Table 3.2). Retrofitting existing thermal power plants with closed-loop cooling systems can significantly reduce water withdrawal, but it involves costs from $100 per kilowatt (kW) up to $1 000/kW (BNEF, 2012).

The efficiency of transmission and distribution networks is also compromised by a rise in ambient temperature. Taking into account the effects of temperature changes on thermal power plant efficiency, transmission line capacity, substation capacity and peak demand, a higher temperature scenario will either require additional peak generation capacity and additional transmission capacity, or a greater demand-side response at peak times. Even considering the gradual impacts of climate change, the accumulation of relatively small

4. In the case of nuclear plants, a 1 °C increase in the temperature of the cooling water yields a decrease of 0.12-0.45% in the power output (Durmayaz and Sogul, 2006).

changes in performance will have a significant impact on the availability of generating capacity and change the cost of electricity.[5]

Electricity generation and transmission and distribution networks are also at significant risk from extreme weather events, which can result in infrastructure being damaged or destroyed and consumers losing their supply, potentially for long periods. Weather-related disturbances to the electricity network in the United States have increased ten-fold since 1992 and, while weather events accounted for about 20% of all disruptions in the early 1990s, they now account for 65% (Karl, Melillo and Peterson, 2009).

3

Table 3.2 ▷ Review of the regional impact of water temperature and water scarcity on thermal power generation

	Water temperature	Water scarcity
Europe	Nearly 20% of coal-fired power generation will need added cooling capacity. About 1 °C of warming will reduce available electric capacity by up to 19% in summer in the 2040s.	
United States	About 1 °C of warming will reduce available electric capacity by up to 16% in summer in the 2040s.	60% of existing coal-fired power plants (347 plants) are vulnerable to water demand and supply concerns.
India		Severe water scarcity will amplify competition for water and determine thermal plants competitiveness and location. Around 70% of planned power capacity is in locations considered either water stressed or water scarce.
China		Water constraints could make the expected increase in thermal power output unachievable, in particular, as 60% of thermal power capacity is in northern China, which has only 20% of freshwater supply.

Sources: Jochem and Schade (2009); Vliet, *et al.* (2012); Elcock and Kuiper (2010); BNEF (2013); Sauer, Klop and Agrawal (2010) and IEA analysis.

Renewable energy

Renewable energy can also be affected by climate change. Hydropower currently accounts for 16% of electricity generation globally, but climate change will affect the size and reliability of this resource in the future. Water discharge regimes will change, with run-off from rivers in areas dominated by snow melt potentially occurring earlier in the year, at levels temporarily higher than previously and with an amplification of seasonal precipitation cycles. At the global level, output from hydropower is likely to change little,

5. For gas-fired power plants, a 10 °C change in ambient temperature can lead to a decrease of over 6% in net electric power for a combined-cycle plant (Ponce Arrieta and Silva Lora, 2005). According to Jochem and Schade (2009), transmission losses could increase by 0.7% up to 2050 in Europe, while Sathaye, *et al.* (2013) find that electricity losses in substations could increase by up to 3.6% in California by 2100.

but there will be significant regional variations, with increased generation potential in some regions and reductions in others. The impact of climate change is particularly important in countries that rely heavily on hydropower for electricity generation, such as Brazil and Canada. Hamadudu and Killingtveit (2012) find that, for a warming of about 2 °C by 2050 compared with pre-industrial levels, hydropower output increases in Russia, the Nordic countries and Canada by up to 25%, while it decreases in southern Europe and Turkey. More northerly parts of Latin America, including northern Brazil, are expected to see hydropower output decrease, but it is expected to increase in southern Brazil and Paraguay. In the northwest United States, some analysis points to a 20% reduction in hydropower generation by the 2080s (Markoff and Cullen, 2008). Hydropower plants can adapt to climate change with structural measures, such as increasing the size of reservoirs, modifying spillway capacities and adapting the number and types of turbines.

How climate change will impact other renewable energy sources is less well understood and subject to strong regional differences. The effect on wind power resources is difficult to assess due to the complexity of representing near-surface wind conditions in global climate models (Pryor and Barthelmie, 2010). Also, it is not only the overall electricity generation potential from wind which is impacted by climate change, but also seasonal patterns. For example, electricity generation from wind power could decrease by up to 40% in the northwest of the United States in the summer (Sailor, Smith and Hart, 2008). The effect of climate change on the operation and maintenance of wind turbines will depend on the frequency of extreme wind speeds and the possible reduced occurrence of icing. Future electricity generation from solar photovoltaics (PV) depends not only on solar radiation but also on ambient temperature and, for regions at higher latitudes, on snow cover. For a level of warming similar to our New Policies Scenario, research suggests that electricity generation from solar PV could decrease by 6% in Nordic countries in 2100, relative to a scenario without climate change (Fenger, 2007).

Biomass production, including biofuels, is affected not only by an increase in average temperature, but also by changing rainfall patterns, the increase in the carbon-dioxide (CO_2) concentration and extreme weather events, such as storms and drought. Higher CO_2 levels and a limited temperature increase can extend the growing season, but more frequent extreme weather events or changes in precipitation patterns can more than offset these positive impacts. The impacts will vary by region and type of biomass. For example, it is expected that the production of many biomass crops will increase in northern Europe but decrease in southern Europe, with Spain particularly vulnerable due to increased drought (Tuck, *et al.*, 2006).

Climate resilience

Climate change and weather extremes directly affect energy supply in a number of ways and illustrate how mitigation and adaptation become inextricably linked. Strong action to reduce greenhouse-gas emissions will reduce the need to invest in climate adaptation but will not eliminate it. Even a global average temperature rise of 2 °C is going to demand some adaptation. Unless the resilience of our energy system to climate change is considered more explicitly, energy supply and transformation will be exposed to greater physical risks, which will increase capital, maintenance and insurance costs, impair energy supply reliability and accelerate the depreciation and deterioration of assets.

The climate resilience of the energy system could be enhanced in a number of ways. In terms of overall preparedness and planning, emergency response and co-ordination plans can be developed that cover critical energy infrastructure that is vulnerable to the impacts of climate events, such as in response to storms, floods and droughts (NCADAC, 2013). Energy facilities can be relocated or "hardened" to such events, with additional redundancy measures also built into their design. Additional peak power generation capacity, back-up generation capacity or distributed generation can improve power sector resilience. Also, grid systems can be physically reinforced (strengthening overhead transmission lines or using underground cables), intelligent controls can be introduced and networks can be decentralised (limiting the impact of system failures). In those regions vulnerable to water scarcity, power plants can move towards recirculating, dry (air-cooled) or hybrid cooling systems for power plants, as is happening in South Africa, or using non-freshwater supplies, as is the case in oil production in parts of the Middle East. On the demand side, zero-energy buildings, demand-response capabilities, such as smart grids and generally improved levels of energy efficiency can help either reduce the likelihood of system failures caused by power demand spikes or reduce the impact of a supply failure.

Governments need to design and implement policy and regulatory frameworks that encourage prudent adaptation to the impacts of climate change and help to overcome barriers across different sectors of the economy. There have recently been some encouraging developments in this respect, with the European Commission publishing a strategy intended to make adaptation a central consideration in European Union sector policies (European Commission, 2013), and the US President's Council of Advisors on Science and Technology stating that "a primary goal of a national climate strategy should be to help the Nation prepare for impacts from climate change in ways that decrease the damage from extreme weather...and ways that speed recovery from damage that nonetheless occurs" (US PCAST, 2013). As governments encourage action, the private sector needs to reflect on how best to bring the risks and impacts of climate change into its investment decision-making, especially for critical or long-lived energy assets.

Economic impact of climate policies on the energy sector

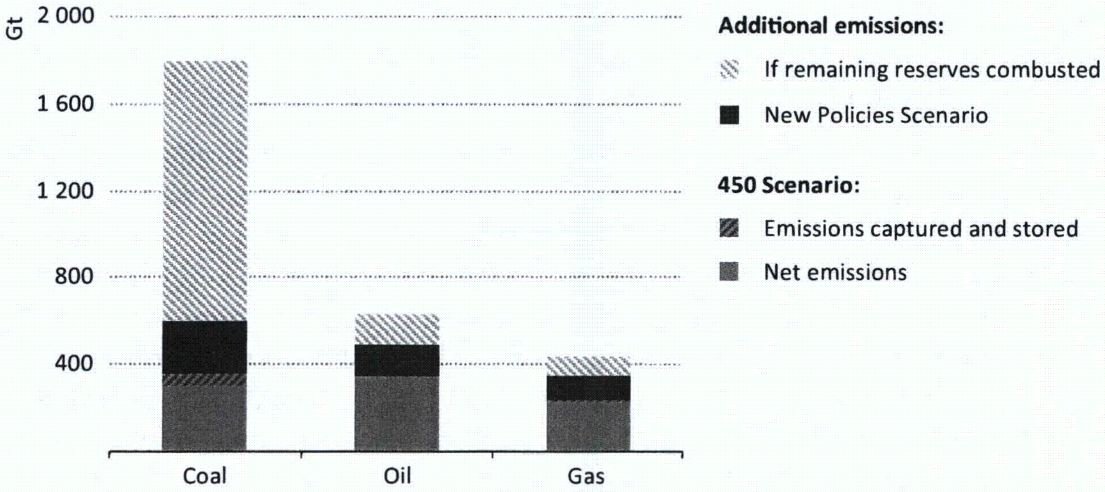
Moving on from the issue of how climate change itself will affect the energy sector, this section analyses the related question of the impact on energy sector assets and revenues of the adoption by governments of more or less stringent policies to avoid or limit climate change. In considering the capital allocation and revenue implications of the transition to a low-carbon energy system, it draws on the New Policies Scenario and the 450 Scenario of the *World Energy Outlook 2012 (WEO-2012)*, which reflect differing levels of climate action (see Chapter 1, Box 1.3, for information on these scenarios or refer to *WEO-2012* for full details). The policy changes in the New Policies Scenario, which include both climate and other policies, are those that the energy sector can already expect to deal with as part of normal business: they have already been announced and many are already being implemented. The 450 Scenario goes much further, tracing a plausible trajectory to the international objective of achieving a 2 °C climate goal and identifying the associated additional policies. We focus on the 450 Scenario, rather than the 4-for-2 °C Scenario discussed in Chapter 2, primarily because the emphasis is on the longer-term outlook (whereas there is particular emphasis in the 4-for-2 °C Scenario on the period to 2020) and the longer time horizon is more relevant to the measurement of the economic impact of climate policy on energy sector investment decisions.

We start by examining, first, the extent to which existing proven fossil-fuel reserves are consumed under different climate policy paths and, second, the extent to which our current energy infrastructure has already "locked-in" future carbon-dioxide emissions. We then analyse, by sector, the impact of different climate policies on the future gross and net revenues of power generation, upstream oil and gas, and coal mining. While recognising that many new developments can result in energy sector assets becoming "stranded", such as the impact of the shale gas boom on LNG import terminals in the United States, we seek to analyse the particular risks associated with stronger climate change policies. For this analysis, we define stranded assets as those investments which have already been made but which, at some time prior to the end of their economic life (as assumed at the investment decision point), are no longer able to earn an economic return, as a result of changes in the market and regulatory environment brought about by climate policy. This might, for example, include power plants that are retired early because of new emissions regulations, or oil and gas fields that, though discovered, are not developed because climate policies serve to suppress demand. In measuring the scale of the loss associated with these stranded assets, we do not include the energy production or capital recovery up to the point the asset becomes uneconomic, but only the lost element after this point. We do not seek to estimate here the impact that changes in assets or revenues could have on the financial valuation of energy companies, which can be affected by a very broad range of factors.

Existing carbon reserves and energy infrastructure lock-in

The energy sector has always devoted considerable resources to finding, and then proving up, fossil-fuel reserves in the expectation that they will one day be commercialised. The extent to which these reserves – which can be regarded as carbon reserves, that is fossil-fuel reserves expressed as CO_2 emissions when combusted – are actually consumed and the CO_2 emissions released differs by fuel and scenario, according to the nature and intensity of the climate policies adopted. In our 450 Scenario, more than two-thirds of current proven fossil-fuel reserves are not commercialised before 2050, unless carbon capture and storage (CCS) is widely deployed.[6] More than 50% of the oil and gas reserves are developed and consumed, but only 20% of today's coal reserves, which are much larger (Figure 3.5). Of the total coal- and gas-related carbon reserves, 3% are consumed in CCS applications where the CO_2 emissions are stored underground. In our less stringent New Policies Scenario, there is higher consumption of fossil fuels but at the price of failing to achieve the 2 °C trajectory. Even in the absence of any further action on climate change, not even those allowed for in the New Policies Scenario, around 60% of world coal reserves would remain underground in 2050.

Figure 3.5 ▷ Potential CO_2 emissions from fossil-fuel reserves and cumulative emissions by scenario to 2050



The profile of the existing global energy infrastructure (including facilities under construction) means that four-fifths (550 gigatonnes [Gt] CO_2) of the total volume of CO_2 emissions that the energy sector is allowed to emit under a 2 °C trajectory up to 2035 are already locked-in simply by the assumption that it will continue to operate over its normal economic life. Assuming no large shifts in relative fuel prices or technological breakthroughs, the emissions expected to come from this infrastructure could only be avoided if policies were introduced which had the effect of causing its premature retirement or costly refurbishment. Around half of the locked-in emissions originate from the power sector and 22% from industry, as the facilities in these sectors typically have a long life. The share of power generation in total locked-in emissions is highest in India, at 60%, closely followed by China, Russia and the United States. In India and China, this is because the electricity sector relies to a relatively large extent on recently installed coal-fired power plants, which are set to remain in operation for decades, while in the United States, large (relatively old) coal power plants currently lock-in a considerable

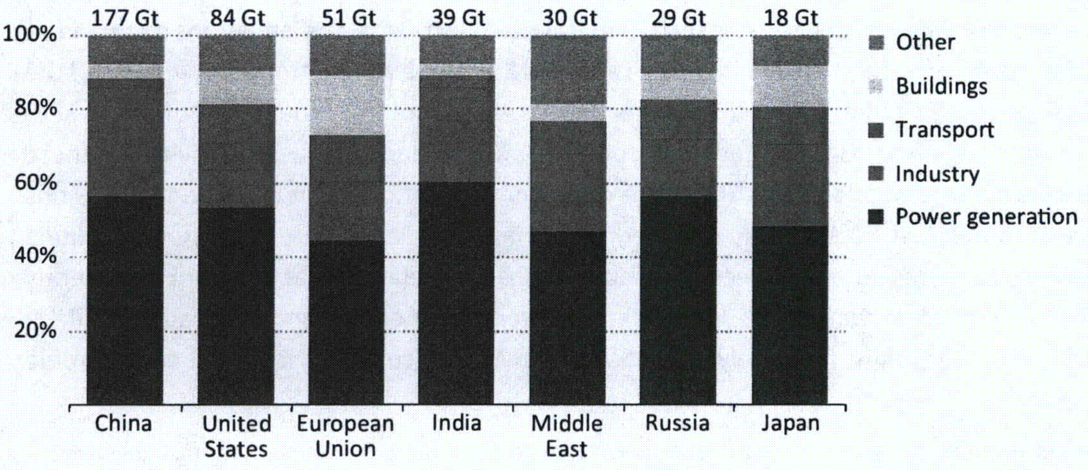
6. Proven reserves are usually defined as discovered volumes having a 90% probability that they can be extracted profitably. Ultimately recoverable resources (not discussed here) are much larger and comprise cumulative production to date, proven reserves, reserves growth (the projected increase in reserves in known fields) and undiscovered resources that are judged likely to be produced using current technology.

volume of emissions. The share of locked-in emissions for industry in China is around 30%, twice the level of that in the European Union: China's industry is dominated by the iron and steel and cement sub-sectors, which have a relatively young age profile, indicating continued operation well into the future.

The share of locked-in emissions from transport (9%) and buildings (6%) is lower, as the bulk of the energy-consuming infrastructure in these sectors typically does not remain operational for more than around fifteen years. In the United States, the transport sector has a relatively high share (18%) of total locked-in emissions, since transport is responsible for a relatively high proportion of overall energy-related CO_2 emissions. Buildings account for 15% of locked-in emissions in the European Union, the highest share of all regions, due to the importance of space heating in Europe's energy systems. Another 6% of locked-in emissions results from other forms of energy transformation (mainly refineries, and oil and gas extraction), 4% from non-energy use (mainly petrochemical feedstock and lubricants) and 1% from agriculture (including field machinery).

In non-OECD countries, infrastructure that exists or is under construction locks-in 360 Gt CO_2 from 2011 to 2035, led by China, India, the Middle East and Russia, while, in OECD countries, the figure is 195 Gt CO_2, led by the United States and the European Union (Figure 3.6). The outlook in non-OECD countries is mainly a consequence of the infrastructure expansion that has taken place over the past decade and the amount that is currently under construction. However, the extent of the continuing rapid expansion of energy infrastructure in non-OECD countries presents an important window of opportunity to avoid further lock-in of emissions by adopting efficient, low-carbon installations. The challenge and opportunity for OECD countries lies, rather, with the replacement strategy adopted for the large amount of ageing fossil-fuel based infrastructure that could be retired, or its use lowered, over the next few decades.

Figure 3.6 ▷ CO_2 emissions locked-in by energy infrastructure in place and under construction in 2011 by region and sector through to 2035



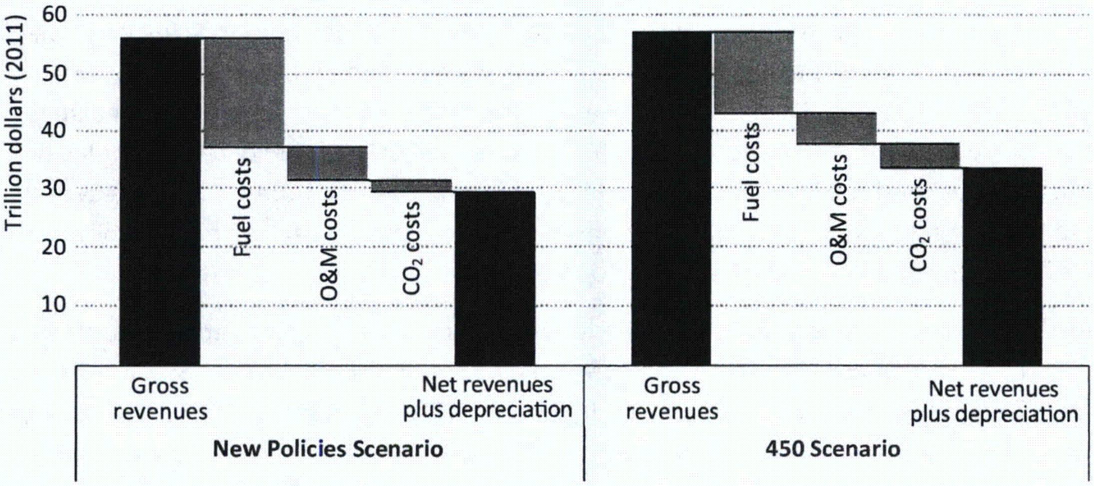
Note: Other includes energy transformation, non-energy-use and agriculture.

Power generation

Revenues

In the power sector, gross revenues are made up of a combination of wholesale electricity revenues (volume of electricity generation multiplied by the wholesale electricity price) and support received from governments for renewables (volume of supported renewables generation multiplied by the level of support). Wholesale electricity revenues account for the vast majority of gross revenues, with government support for renewables accounting for only a small share in our scenarios (just over 6% of gross revenues in the 450 Scenario and slightly less than this in the New Policies Scenario). Different market structures directly affect gross revenues by establishing the way in which wholesale electricity prices are formed. In a liberalised market, the price is based on the short-run marginal costs of power generation. In an integrated monopoly, wholesale prices largely reflect the average costs of generation (Box 3.3).

Figure 3.7 ▷ Power sector gross revenues and operating costs by scenario, 2012-2035



Note: O&M = operation and maintenance.

On a consistent basis across scenarios, gross revenues in the power sector (from 2012 to 2035) are $1.3 trillion (in year-2011 dollars) higher in the 450 Scenario than in the New Policies Scenario (Figure 3.7).[7] The higher gross revenues result from a combination of lower electricity demand and higher electricity prices, with the latter effect proving slightly larger.[8] Over the projection period, total electricity generation is nearly 60 000 TWh, or 8%, lower in the 450 Scenario than in the New Policies Scenario, a reduction equivalent to

7. In the calculations made in this section, aggregate gross revenues for existing and new power plants are comparable across scenarios. However, net revenues are discussed separately for existing and new plants. This is because of data deficiencies. For existing plants, investment data is not available for all plants so we present net revenues before accounting for depreciation. For new plants, investment costs are based on known assumptions so we are able to present net revenues after accounting for depreciation costs.

8. Wholesale electricity prices are calculated endogenously within our World Energy Model. For more information, see "World Energy Model Documentation: 2012 version" at *www.worldenergyoutlook.org*.

almost three times annual world generation in 2010, but wholesale electricity prices are 16% higher, on average, in 2035. The change in electricity prices results from a combination of lower fossil-fuel prices, higher overall CO_2 costs (higher and more widespread CO_2 prices but lower levels of CO_2 emissions in the 450 Scenario) and capacity additions that are more capital intensive. Operation and maintenance (O&M) costs are similar across the two scenarios, as the reduction in costs that comes from phasing out some fossil-fuel plants are offset by increased reliance on technologies with higher maintenance costs per unit of capacity, such as CCS and nuclear.

For all power generation capacity, net revenues before accounting for depreciation[9] ("net revenues plus depreciation" in Figure 3.7) are $4.3 trillion higher in the 450 Scenario than in the New Policies Scenario. These revenues essentially provide for the recovery of investment costs and a financial return on investment.[10] Depreciation costs for new capacity are $1.4 trillion higher in the 450 Scenario than the New Policies Scenario, as this scenario requires more generating capacity to be built to offset the lower utilisation factor of many renewables compared to the fossil alternative and generally more capital-intensive technologies. This additional cost is more than offset by lower fuel and O&M costs, which are $4.5 trillion (19%) lower than in the New Policies Scenario through to 2035. This is due to lower electricity demand, lower fossil-fuel prices and a more marked transition to renewables and nuclear with low or no fuel costs. CO_2 costs are $1.5 trillion higher in the 450 Scenario, with prices reaching $95-120 per tonne in many regions in 2035. While higher CO_2 prices increase wholesale electricity prices (and therefore consumer bills), this revenue can potentially be recycled back to consumers in ways that partially offset the economic impact of electricity price rises, without compromising climate policy outcomes.

For existing power generation capacity, net revenues before accounting for depreciation[11] are at similar levels in the 450 Scenario and the New Policies Scenario, at around $15.6 trillion. In the 450 Scenario, net revenues increase by around $900 billion each for both existing nuclear and renewables capacity (that receive the market price in liberalised markets), compared with the New Policies Scenario (Figure 3.8). This gain offsets a similar loss in net revenues by fossil-fuel plants of $1.9 trillion. Coal power plants without CCS bear the burden of the relative revenue reductions in the 450 Scenario, as rising CO_2 costs and reduced operating hours outweigh the impact of lower fossil-fuel prices, and power plants with higher emissions are more affected than those with lower emissions. Net revenues from gas-fired power plants increase slightly overall in the 450 Scenario, compared with the New Policies Scenario, with higher revenues from more efficient power plants, and some coal to gas substitution, more than offsetting lower revenues from less efficient gas plants.

9. This equals gross revenues minus operation and maintenance costs, the cost of fuel inputs and payments for CO_2 emissions in markets with a carbon price.

10. The weighted average cost of capital (WACC) is assumed to be 8% in OECD countries and 7% in non-OECD countries for all technologies.

11. Investment data relating to all existing power plants are not available, preventing a robust estimation of depreciation costs. The omission of these costs means that our calculation of "net" revenues is artificially high but, as the same approach is adopted in all scenarios, it is reasonable to compare across them.

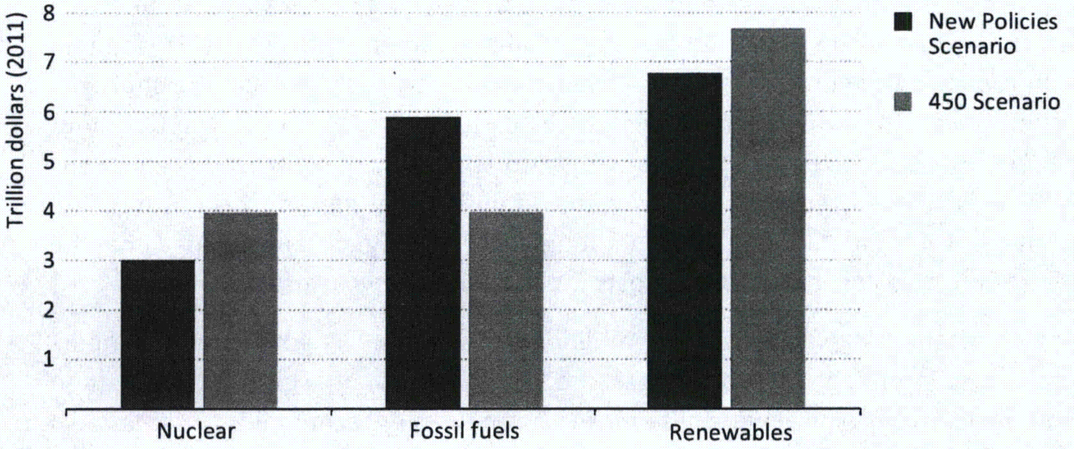
Box 3.3 ▷ Implications of decarbonisation on power markets

Market design reforms are currently envisaged in several countries where there is a concern that liberalised markets might not be able to stimulate sufficient investment in new capacity. In liberalised markets, the spot price typically reflects the short-run marginal costs of the last power plant called to respond to demand. The hourly or half-hourly price received by all power generators is typically set by the costs of the most expensive plant required to be dispatched during that period. This ensures that the price is sufficient to cover the operating costs of all generators, but it may be insufficient to also cover investment costs (or encourage new investment).

In some instances, generators earn additional revenues via government support mechanisms intended to encourage the deployment of selected generation technologies. This is typically the case for some renewables technologies but may also be considered for other low-carbon technologies, such as fossil-fuel plants using CCS. As these technologies become more competitive, the level of support is expected to be reduced (and ultimately phased out) for new capacity. The capacity additions that result from such support mechanisms tend to lower the wholesale market price and reduce anticipated operating hours of conventional plants, exacerbating the problem of recovering investment in new plants, making it harder for pre-existing plants to recover their investment costs and harder to attract investment in new capacity that does not benefit from such support. Moreover, the introduction of variable renewables requires significant amounts of flexible capacity available to be dispatched to guarantee the reliability of supply. In order to ensure adequate generation capacity, several countries are considering the introduction of either a capacity payment mechanism or looking at the possibility of allowing very high wholesale prices during times of scarcity, for example, periods when variable renewables are not operating. Capacity additions that benefit from support mechanisms generally receive a significant amount of their revenues from outside of the wholesale market, *e.g.* a guaranteed feed-in tariff, and therefore do not suffer from this problem.

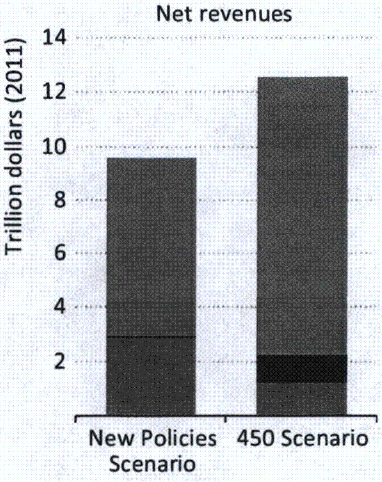
While the existing frameworks of many liberalised markets will be able to encourage significant decarbonisation of the power mix, they will struggle to deliver a major transition towards a decarbonised world. Further changes to market designs are likely to be needed. This is particularly true for those markets that are expected to rely on high levels of variable renewables. This is because, in the absence of significant amounts of storage capacity or smart grid measures (to shift demand away from peak times), the variable nature of their supply means they may be unable to sell into the market when prices are highest, limiting their ability to recover their investment costs from the wholesale market. On the other hand, the low variable costs of these sources of generation mean that, under existing market structures, wholesale prices could be reduced to very low levels – possibly below the levels needed to recover their own investment costs – unless there is some form of additional compensation. Improving existing market designs and developing new ones for competitive power systems will therefore be an essential feature of the transition towards a decarbonised world.

Figure 3.8 ▷ Net revenues before accounting for depreciation for existing power plants by scenario, 2012-2035



For new power generation capacity, net revenues after accounting for depreciation are $3 trillion higher in the 450 Scenario than in the New Policies Scenario (Figure 3.9). The general shift towards a 2 °C goal is reflected in the relative change in net revenues from the New Policies Scenario to the 450 Scenario, with renewables, nuclear and fossil-fuel plants fitted with CCS enjoying higher revenues as climate policies strengthen. Net revenues from new renewables capacity are 55% higher in the 450 Scenario than in the New Policies Scenario while the capacity additions over the projection period are 46% higher. In the 450 Scenario, new renewables capacity provides nearly two-thirds of all net revenues from new capacity in the power sector.

Figure 3.9 ▷ Net revenues after accounting for depreciation and investments for new power plants by scenario, 2012-2035



Investments ($2011, billion)	New Policies Scenario	450 Scenario
Renewables	6 020	8 778
Nuclear	942	1 513
Fossil-fuel plants fitted with CCS	216	950
Fossil-fuel plants without CCS	2 507	1 803

The 450 Scenario sees nearly 1 400 GW of additional renewables capacity in 2035, compared with the New Policies Scenario. Fossil-fuel power plants without CCS play a significantly smaller role in the power sector in the 450 Scenario, with two-fifths less new capacity

built than in the New Policies Scenario. Furthermore, higher carbon prices reduce the net revenues of new fossil-fuel plants without CCS in the 450 Scenario. In contrast, new plants with CCS see a marked increase in capacity and net revenues, reaching 570 gigawatts (GW) of installed capacity in 2035. Nuclear capacity additions increase by 60% in the 450 Scenario and the net revenues for each unit of capacity are higher, on average, due to elevated wholesale electricity prices.

Combining the economic prospects for existing and new power plants, net revenues (after accounting for depreciation) for the power sector are $3 trillion higher in the 450 Scenario than in the New Policies Scenario. Stated simply, financial opportunities could improve in the 450 Scenario for power producers with a portfolio of low-carbon technologies, including harnessing the benefits of CCS as a form of asset protection strategy.

Implications for assets

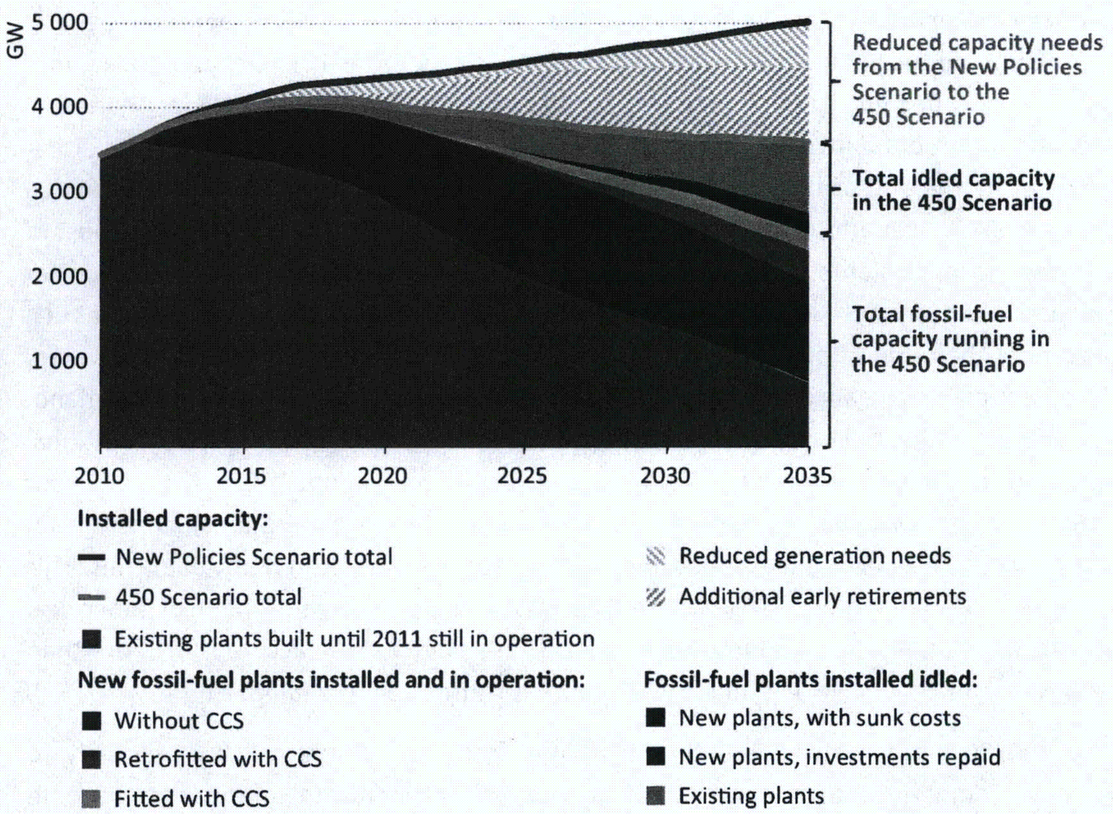
An important effect of the decarbonisation of the power sector in the 450 Scenario is to cause many older, inefficient, fossil-fuel plants to be either idled or retired before the end of their anticipated technical lifetime,[12] and some power generation capacity additions under construction to become uneconomic and be retired early, despite originally appearing to be economically sound investments. An additional 2 300 GW of fossil-fuel plants are either retired before the end of their technical lifetime (37%), idled (47%) or retrofitted with CCS (16%) in the 450 Scenario, compared with the New Policies Scenario (Figure 3.10). Most of the retired or idled plants do recover their investment cost, but they are in operation for fewer years than in the New Policies Scenario. Older, inefficient plants are retired early as CO_2 costs render their operations uneconomic, but their investment costs have been recovered. Idled power plants remain available and may occasionally run in periods of strong demand, when the economics allow. Some existing, but relatively new, plants require additional investment to retrofit them with CCS, so that they can remain in operation. Almost 50% of the plants retired or idled are inefficient subcritical coal-fired power plants, as rising CO_2 prices make them uneconomic, squeezing them out of the market in many countries. This share is significantly higher (75%) in non-OECD Asia, where a large number of subcritical coal plants have been installed in recent years. These plants alone account for more than one-third of the 1 940 GW of global capacity that is retired early or idled.

In the 450 Scenario, around 2 000 GW of new fossil-fuel plants are built globally to meet rising demand and, in some cases, to replace old inefficient plants that become uneconomic. Almost 30% of these new plants are fitted with CCS, two-thirds of these as a retrofitting operation, as the technology becomes more competitive at scale. Just under one-quarter of the anticipated new fossil-fuel plants are currently under construction and they may face difficulties recovering their investment costs if they have not taken the costs of decarbonisation fully into account. A smaller, but still significant, number of

12. A power plant may, for example, have an economic lifetime of 30 years (the period over which it recovers its capital investment) but be capable technically of operating for longer, perhaps 50 years.

new plants are idled: of this 260 GW of capacity, 165 GW are idled before repaying their investment costs, resulting in an unrecovered sunk cost of around $120 billion, or about 40% of the initial investment. The remaining 90 GW of new power plants that are idled recover their investment costs. Idled plants can still be given new economic life, reducing economic losses, if, at some point, they are retrofitted with CCS. Such retrofits would be expected to apply to the most efficient plants where the investment case is strongest (CCS reduces power plant efficiency in the order of 8-10%). The availability of CCS technology, not only for the construction of new power plants but also for the retrofitting of existing power plants, is a key assumption in our assessment of sunk costs, as the deployment of CCS technology has yet to be fully commercialised, making this a key challenge for the realisation of the 450 Scenario (see Chapter 2 section on the relevance of CCS).

Figure 3.10 ▷ World installed fossil-fuel power generation capacity in the 450 Scenario relative to the New Policies Scenario

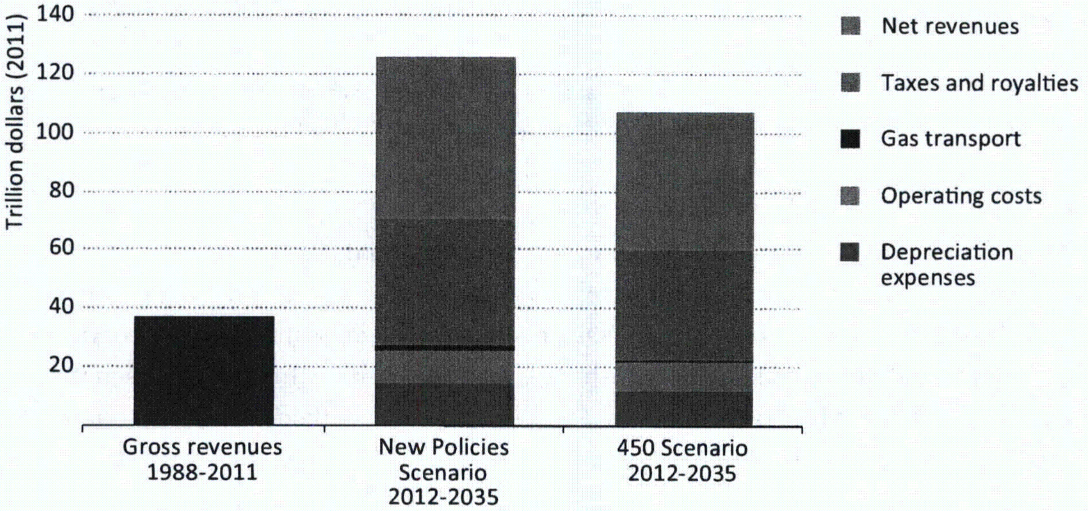


Upstream oil and natural gas

Revenues

The gross revenues of oil and gas companies are determined by two key factors: the level of production and the prevailing prices. In the 450 Scenario, oil and gas gross revenues are more than $105 trillion from 2012 to 2035 (in year-2011 dollars), nearly three times higher than the level of the last two decades, but lower than in the New Policies Scenario which is around $125 trillion (Figure 3.11). Oil accounts for 70% of the gross revenues and natural gas for 30% in the 450 Scenario. Oil demand peaks before 2020 and then declines, while gas demand continues to increase through to 2035, ending 17% higher than 2011. Oil prices average $109 per barrel (in year-2011 dollars) in the 450 Scenario ($120 per barrel in the New Policies Scenario), while the course of natural gas prices varies regionally: gas prices decline in Japan, remain broadly stable in Europe and increase in the United States (see Chapter 1, Table 1.1 for our price assumptions).

Figure 3.11 ▷ Cumulative world oil and gas gross upstream revenues by component and scenario

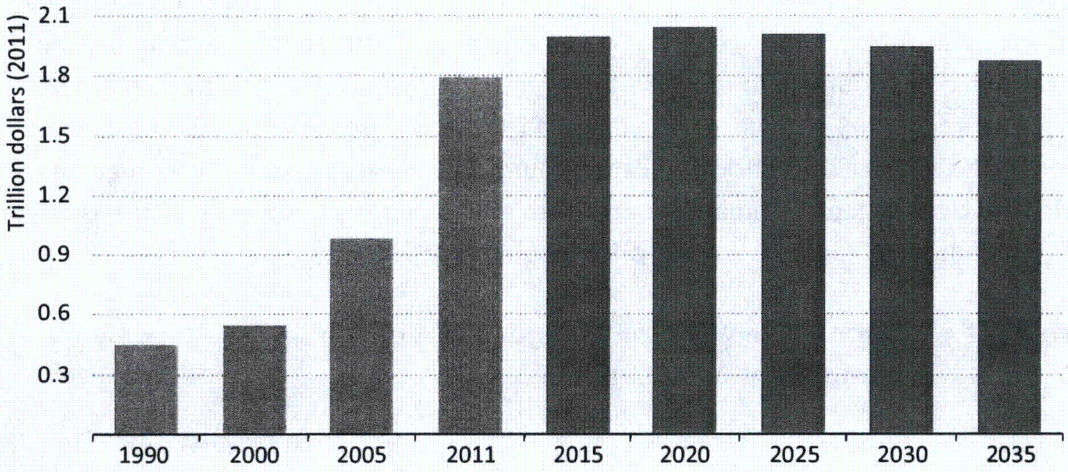


Notes: Tax and royalty rates can vary between scenarios but are kept constant for this comparison. In cases where production is dominated by national oil companies, the definition of taxes is somewhat arbitrary; here we assume tax rates comparable to international averages.

Cumulative net revenues, *i.e.* gross revenues, minus operating costs, gas transport, taxes and royalties and depreciation expenses, are projected to be $47 trillion in the 450 Scenario, their level in 2035 being lower than in the New Policies Scenario, but higher than in 2011 (Figure 3.12). Net revenues from gas grow throughout the projection period, mainly driven by increasing demand, while net revenues from oil increase initially but peak before 2020 and then start to decline, as demand and prices decrease. Net revenues over the period are estimated to correspond to around a 25% return on capital.[13]

13. Assuming international oil companies typically operate with 10% risk-free rates of return, and up to 20% in regions carrying a risk premium, with the average return on capital number being boosted by the contribution of national oil companies operating in low production cost areas (based on our conservative definition of tax rates).

Figure 3.12 ▷ World upstream oil and gas net revenues in the 450 Scenario



Note: The absence of comprehensive historical data means that net revenues for previous years are estimated by applying the same gross-to-net revenues ratio that is used for future years.

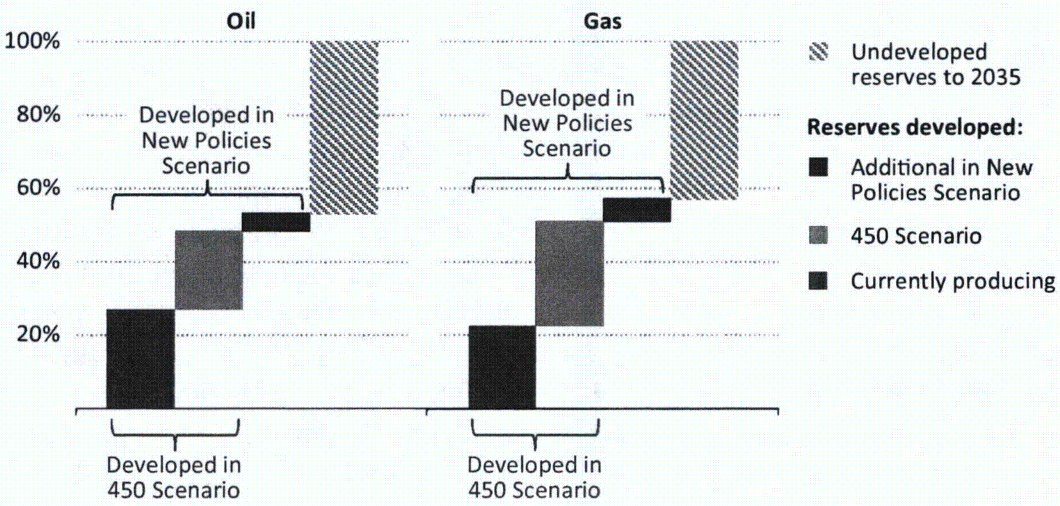
Implications for upstream oil and gas assets

Upstream oil and gas assets can become stranded if existing fields do not operate at as high a level as originally planned, if they need to be retired before the end of their economic life, or if a field at which exploration costs have been incurred does not go into production by 2035 (the end date of our calculations). There is an important distinction between those oil and gas fields that are in production today and existing or new fields that, depending on demand, might be developed (and therefore start producing) at some point before 2035.

Over the period to 2035, the level of production from oil and gas fields that are producing today is the same in the 450 Scenario and the New Policies Scenario, as their production remains economically viable in both cases. The investment in many of these fields has already been recovered and their level of operation largely depends on the optimal depletion rate and the additional costs associated with continuing production. Thus, the policies in the 450 Scenario do not introduce significant new risks that currently producing oil or gas fields will be forced out of operation.

In the case of oil and gas fields that have yet to start production, or have yet to be found, the lower level of demand in the 450 Scenario means that fewer of them justify the investment to bring them into production (or to find them) before 2035 (Figure 3.13). This means that some fields – those that have been found but are not brought into production by 2035 – do not start to recover their exploration costs in this timeframe. Relative to the level in the New Policies Scenario, the additional risk of stranding assets in the 450 Scenario affects 5% of proven oil reserves and 6% of proven gas reserves, all of which have yet to be developed. The economic burden of this is relatively limited as, in the case of fields yet to be developed, the main impact relates to exploration costs (typically around 15% of investment in a new field) which are not recovered by 2035, at least some of which could be recovered in the longer term. In the case of fields yet to be found, avoided exploration and development costs offset the lost potential future revenue opportunity.

Figure 3.13 ▷ Development of proven oil and gas reserves by scenario



Upstream oil and gas sector assets can become stranded for a range of reasons, of which new climate policies is just one, but our analysis suggests that a companies' or countries' vulnerability to this specific risk may be greater if their asset base is more heavily weighted towards those that are not yet developed and towards those that have the highest marginal production cost (unless its development is driven by broader factors, such as energy security). Over the lifetime of upstream oil and gas assets, their financial value and economic viability may be appraised often, including when: a company compiles its accounts; a company takes investment decisions related to the asset (such as whether to develop a field, which is often tested under a range of cost-benefit assumptions); and, ownership of the asset changes. These, and other, reasons may mean that the financial impact of stranded assets is realised relatively gradually over time and across several parties.

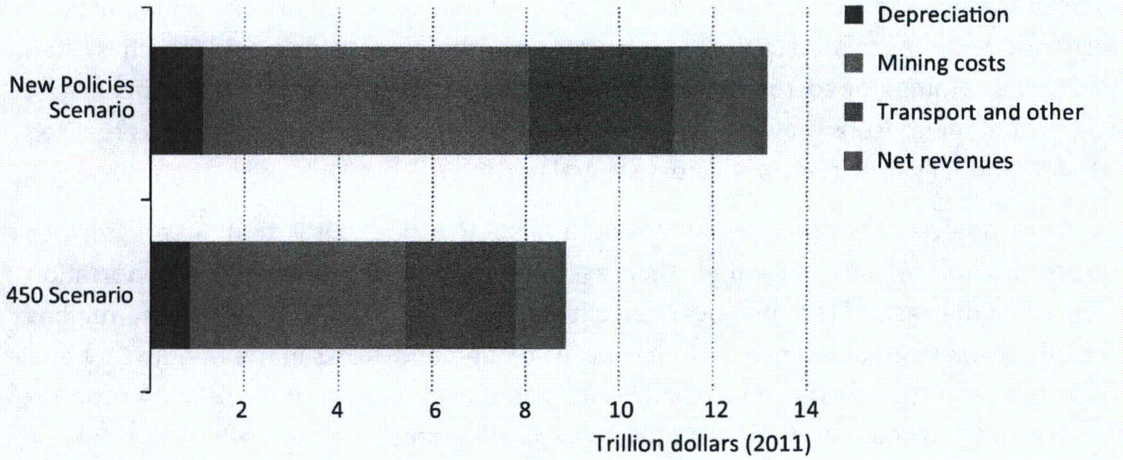
While not analysed here in detail, there is also the possibility that assets further downstream will become stranded, such as in refining, LNG plants and transportation networks. In the case of refining, over-capacity is already a familiar issue in some regions and could worsen under a range of scenarios. As oil demand grows in the Middle East and Asia, these regions have started extensive programmes to expand their refining capacity both to meet internal needs and supply the export market. Lower utilisation rates, or permanent shut down, of refining capacity could result in other regions, such as in Europe and North America, where domestic demand is declining. Within the next decade some 2 mb/d of refining capacity is expected to be idled due to lack of demand, largely irrespective of climate change policies. This will affect not only old and inefficient plants, but also relatively complex facilities that are bypassed by the changing crude and product trade flows (see the focus on refineries in the forthcoming *World Energy Outlook 2013*). In the case of transportation systems, some regions have already built additional pipelines to establish new trade corridors and, given the very long lifetime of such infrastructure, it is possible that utilisation rates would decrease in some areas in the 450 Scenario, increasing the risk of stranded assets.

Coal supply

Revenues

Revenues generated by the global coal industry are a function of the volumes sold to the market and the prices received for the product. Coal prices vary not only by type (steam, coking and brown coal) but also by region, reflecting coal quality, transport costs and infrastructure constraints. Typically, prices for coking coal are markedly higher than those for steam coal, due to the relative scarcity of coking coal and the lack of substitutes in steelmaking, justifying higher mining costs. Brown coal is rarely traded internationally and consequently does not have an international market price. Instead, brown coal is usually combusted in power stations close to the mine, with the cost of mining determining the price. In 2010, global coal production stood at around 5 125 million tonnes of coal equivalent (Mtce), generating for the coal industry gross revenues of around $430 billion (in year-2011 dollars). In the 450 Scenario, which assumes intensified climate policy measures, global coal demand falls by 1.6% per year on average through to 2035 (compared to an average increase of 0.8% per year the New Policies Scenario), with the change in demand leading to a pronounced price drop.

Figure 3.14 ▷ Cumulative world coal gross revenues by component and scenario, 2012-2035



Cumulative gross revenues from coal sales are projected to amount to $8.9 trillion in the 450 Scenario and $13.1 trillion in the New Policies Scenario (Figure 3.14). Coal supply is characterised by its relatively high share of variable mining costs, such as labour, energy, mining materials and spare parts (around 60% of total costs). In the 450 Scenario, the variable mining cost component amounts to $4.6 trillion over the projection period, compared with $6.9 trillion in the New Policies Scenario. Coal is also often hauled long distances using trucks, railways, river barges and ocean-going vessels. Cumulative transport costs stand at $2.3 trillion in the 450 Scenario, compared with $3.2 trillion in the New Policies Scenario. Coal mining is far less capital intensive than oil and gas production, and therefore depreciation is a relatively minor cost component, amounting to around $0.86 trillion in the 450 Scenario and $1.1 trillion in the New Policies Scenario.

Net revenues differ substantially between coal varieties, around two-thirds of the total coming from steam and brown coal (around 85% of global production), with coking coal contributing the remainder. This means around 15% of global coal production earns around a third of the industry's total net revenues. Cumulative net revenues are $0.87 trillion lower in the 450 Scenario compared with the New Policies Scenario. Nearly 55% of this difference can be attributed to a change in price, whereas slightly more than 45% results from volume change. While the price effect is almost entirely borne by coking coal, the demand effect affects mainly steam coal. The level of coking coal production, a key input in the steel industry, declines by a relatively small amount across the scenarios due to the lack of a large-scale substitute for it in this sector. In contrast, there are substitutes for coal in power generation and industry, which see greater take-up of nuclear power and renewables in the 450 Scenario. Although coking coal demand differs by a relatively small amount between the scenarios, prices for coking coal drop sharply for two main reasons: first, coking coal prices are much more sensitive to demand changes than steam coal prices; second, low demand for steam coal allows high quality steam coal to be used for metallurgical purposes, which further depresses the price for coking coal.

Implications for coal assets

Due to the relatively low capital costs involved in coal mining, coal prices need be only slightly above variable costs in order to provide an adequate return on investment. Hence, the risk of incurring large-scale losses on sunk investments is low. Moreover, exploration costs, a classic stranded investment risk, are relatively minor in the coal industry. Reduced demand and lower prices in the 450 Scenario do lead to the closure of the highest-cost mines, for which decreasing market prices do not cover the variable costs of production. These are usually old mines whose competitiveness suffers from deteriorating geological conditions, depletion of the lowest-cost resources and low productivity due to the scale of the operation and inefficient equipment. Such mines typically have already recovered their investment expenditure. Although the danger of stranded assets is, accordingly, limited for the industry as a whole, individual players can still incur substantial losses on sunk investment. This is particularly true for recent investments in fields which also require the large-scale development of railway and handling infrastructure. In the 450 Scenario, coal operators will generally be able to cover their variable costs, but sub-optimal utilisation and depressed prices might result in losses on the underlying investment, highlighting the benefits of early action to identify and mitigate such risks (Spotlight).

SPOTLIGHT

Can corporate strategies help mitigate climate policy risk?

Our 450 Scenario projects an increase in global energy demand relative to today, emphasising that a low-carbon transition is likely to represent a shift in the nature of opportunities within a growing energy market. Corporate strategies that successfully take account of climate policy risk could represent a source of competitive advantage, while failure to do so could result in a company's business model being undermined. Broad, non-exclusive approaches to mitigating climate policy risk might include:

- **Decarbonise:** Invest in technologies that reduce the carbon reserves associated with an existing asset portfolio. Coal companies could invest in underground coal gasification, coal-to-gas, increased washing of coal (to improve efficiency) or develop coalbed methane assets. Oil companies could focus exploration efforts more towards natural gas or invest in enhanced oil recovery utilising CO_2 (or use depleted reservoirs to store CO_2). Power companies could invest in CCS and evolve their portfolio of generation assets towards low-carbon options.
- **Diversify:** Invest in new assets to develop a more diversified portfolio; diluting the risks associated with those that are carbon intensive. Many coal companies are active in other forms of mining (the largest private sector mining companies generate 10%-30% of their revenues from coal). At times, some oil and gas companies have also owned a portfolio of renewable energy assets, such as wind power and biofuels. Geographic diversification of assets can also mitigate the policy risk of a particular market.
- **Delegate:** Take actions to transfer the risk onto other parties willing to accept it, potentially through price hedging instruments or long-term take-or-pay contracts. Price hedging can ensure a fossil-fuel producer receives a particular price for all or part of its supply. A take-or-pay contract can provide a degree of certainty over the volume of fossil fuels to be sold and the revenues to be received.
- **Divest:** Dispose of carbon-intensive assets, particularly those that have higher costs of production, as they are at greater risk of becoming uneconomic.
- **Disregard:** The alternative to the mitigation options above is to accept the risk as it is, together with the associated impacts should it occur. The financial impact will, ultimately, fall upon shareholders. It is therefore notable that *WEO-2012* estimated that nearly three-quarters of global carbon reserves are held by government-owned companies, *i.e.* owned by taxpayers.

Implications of delayed action

Our 450 Scenario, which is consistent with a 50% chance of limiting global temperature increase to 2 °C, assumes a growing intensity of co-ordinated action against climate change from 2014 onwards. Our 4-for-2 °C Scenario (see Chapter 2) takes a slightly different approach, focusing on national short-term actions which can keep the door to 2 °C open without adversely affecting economic growth in any given country, prior to new co-ordinated international action from 2020. Both scenarios depend upon early additional action to tackle climate change, in one form or another. But what if this early action is not forthcoming? We analyse here some of the implications if governments and the energy sector were to delay taking stronger action on climate change, continuing on the path of our New Policies Scenario[14] until 2019 and then having to take sharp corrective action to get back onto a trajectory compatible with a long-term global temperature increase of no more than 2 °C. It is an illustrative case, essentially a "delayed" 450 Scenario, based on the hypothesis that, for a variety of possible reasons, a number of years could pass before a significant new boost is given to national policies and low-carbon investment.

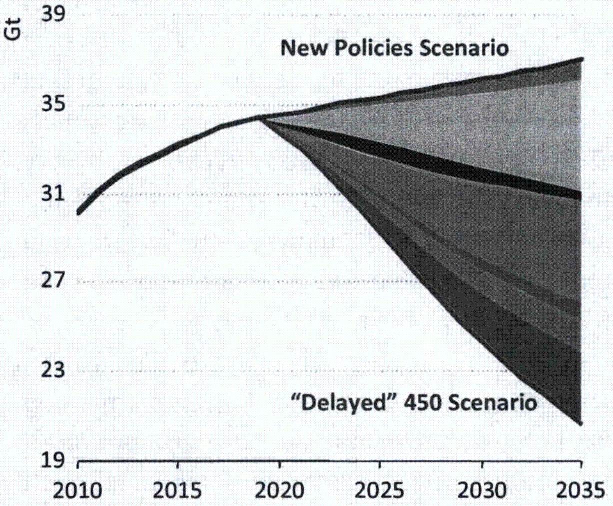
Delaying action on climate change inevitably makes the 2 °C ever more challenging to achieve. In a scenario where there is such a delay, energy-related CO_2 emissions would reach 34.4 Gt in 2019 (as in our New Policies Scenario) but then need, to meet the 2 °C target, to decline even more rapidly after this date, ending at 20.6 Gt in 2035 (Figure 3.15). In essence, the additional emissions in the period to 2020 result in an emissions reduction trajectory thereafter which is even more challenging than our 450 Scenario. The emissions reduction after 2020 is driven by improvements in energy efficiency (particularly in the industry and services sectors), even more rapid deployment of renewable energy technologies in the power sector and widespread adoption of CCS. Energy efficiency is rapidly increased in industry by phasing out old and inefficient facilities in energy-intensive industries, as well as by introducing new efficient motor systems. Energy efficiency in buildings is stepped up by replacing oil- and gas-fired boilers for space and water heating by more efficient ones. In the power sector, additional efficient coal and gas power plants are introduced, with less-efficient plants being operated less or completely retired. The increase in electricity generation from renewables comes mainly from wind power, but also from hydro, bioenergy and solar PV. The key regions affected are China, the United States and India. As well, CCS is very rapidly deployed, with the power sector accounting for nearly 70% of all CCS-related emissions savings, industry for more than 25% and the transformation sector for 5%.

Delaying climate action takes the world beyond the date, estimated to be 2017 in *WEO-2012*, at which then existing energy infrastructure locks-in the entire remaining carbon emissions budget to 2035. The result is that much more costly actions are required subsequently to undo the lock-in effect, including the early retirement of assets, lower utilisation or idling of carbon-intensive capacity and increased investment in CCS retrofitting. In short, delayed action creates more stranded assets in the energy sector. In the power

14. The New Policies Scenario does include cautious implementation of national targets to reduce greenhouse-gas emissions communicated under the 2010 Cancun Agreements.

sector, the delay results in the construction of a greater number of new fossil-fuelled plants up to 2020, around 185 GW of capacity. As a result, 164 GW of power capacity must be either retired or idled (101 GW collectively), or retrofitted with CCS (63 GW), between 2020 and 2035. Developing countries are most exposed to these lock-in effects, as they build two-thirds of the additional fossil-fuel plants constructed up to 2020, many of which are inefficient coal plants. To compensate for emissions from this capacity, an extra 130 GW of plants in developing countries must be retired, idled or retrofitted with CCS after 2020. It follows that, if governments are to stand by their commitment to limit the average rise in the global temperature to no more than 2 °C, developing countries have the most to gain from moving towards clean energy investment more quickly and *vice versa* the most to lose from carbon lock-in. A swift move away from subcritical coal-fired power plants, as highlighted in the 4-for-2 °C Scenario in Chapter 2, is a step in this regard and will help to meet subsequent goals at a lower cost.

Figure 3.15 ▷ World energy-related CO_2 emissions abatement in a "delayed" 450 Scenario relative to the New Policies Scenario



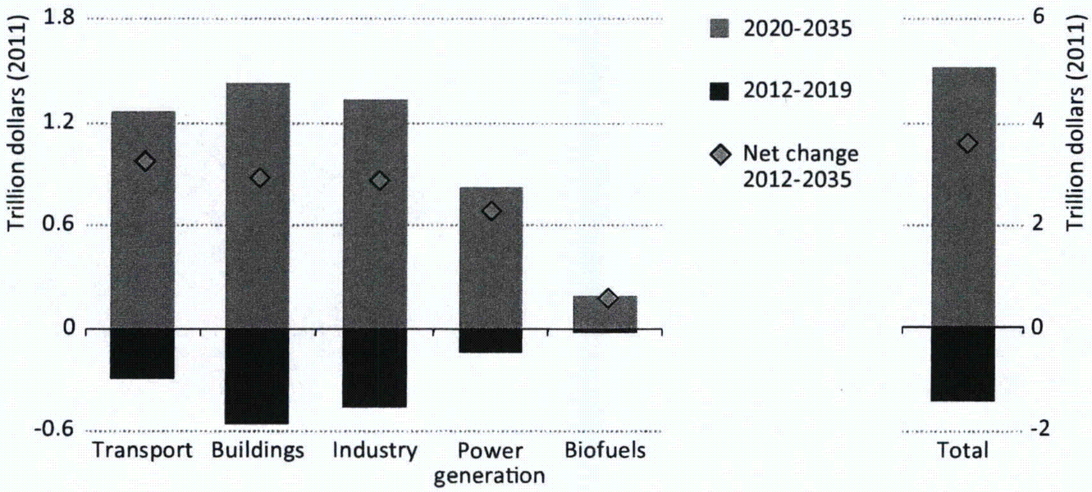
CO_2 Abatement	2025	2035
Demand	5%	5%
End-use efficiency	27%	31%
Power plant efficiency	11%	3%
Fuel and technology switch	2%	2%
Renewables	25%	26%
Biofuels	5%	5%
Nuclear	9%	9%
CCS	15%	20%
Total (Gt CO_2)	6.2	16.4

Analysis of the entire energy system shows that delaying action on climate change is a false economy. Investments of around \$1.5 trillion are avoided in the period to 2020, but an additional \$5 trillion of investments are required between 2020 and 2035 (Figure 3.16).[15] Prior to 2020, investments are notably lower in buildings (around \$0.55 trillion) and industry (around \$0.45 trillion). In buildings, the amount of retrofit in existing buildings is significantly scaled back, while in transport the sales of hybrid and electric cars are lower in the period before 2020. The industry sector avoids investments before 2020 by allowing inefficient old infrastructure to continue to operate for a few more years, reducing investments in more efficient equipment. After 2020, \$1.4 trillion of additional investment

15. Using a 5% discount rate, investment costs avoided prior to 2020 are \$1.2 trillion, while additional investments required after 2020 are \$2.3 trillion. If a 10% discount rate is used, investment costs avoided before 2020 are \$0.95 trillion, while additional investments required after 2020 are \$1.15 trillion.

is required to retrofit buildings across both OECD and non-OECD countries. In industry, additional investment of $1.3 trillion is required to finance large-scale replacement by new equipment, including in furnaces, motors, kilns, steam crackers and boilers. From a technology perspective, early action can increase the potential for accelerated learning and reduced costs. However, delaying action could leave open the possibility of breakthroughs that surpass current technologies.

Figure 3.16 ▷ Change in world cumulative energy investment by sector in a "delayed" 450 Scenario relative to the 450 Scenario



This analysis shows that, if the international community is serious about acting to limit the rise in global temperature to 2 °C, delaying further action, even to the end of the current decade, would result in substantial additional costs in the energy sector. As reflected throughout this report, it highlights the importance of additional mitigation action in the period prior to a new global climate agreement coming into effect, to avoid the waste of creating stranded assets.

Units and conversion factors

This annex provides general information on units, and conversion factors for energy units and currencies.

Units

Coal	Mtce	million tonnes of coal equivalent
Emissions	ppm	parts per million (by volume)
	Gt CO_2-eq	gigatonnes of carbon-dioxide equivalent (using 100-year global warming potentials [GWP] for different greenhouse gases)
	kg CO_2-eq	kilogrammes of carbon-dioxide equivalent
	g CO_2/km	grammes of carbon dioxide per kilometre
	g CO_2/kWh	grammes of carbon dioxide per kilowatt-hour
Energy	Mtoe	million tonnes of oil equivalent
	MBtu	million British thermal units
	Gcal	gigacalorie (1 calorie x 10^9)
	TJ	terajoule (1 joule x 10^{12})
	kWh	kilowatt-hour
	MWh	megawatt-hour
	GWh	gigawatt-hour
	TWh	terawatt-hour
Gas	mcm	million cubic metres
	bcm	billion cubic metres
	tcm	trillion cubic metres
Mass	kg	kilogramme (1 000 kg = 1 tonne)
	kt	kilotonnes (1 tonne x 10^3)
	Mt	million tonnes (1 tonne x 10^6)
	Gt	gigatonnes (1 tonne x 10^9)
Monetary	$ million	1 US dollar x 10^6
	$ billion	1 US dollar x 10^9
	$ trillion	1 US dollar x 10^{12}

Oil	b/d	barrels per day
	kb/d	thousand barrels per day
	mb/d	million barrels per day
	mpg	miles per gallon
Power	W	watt (1 joule per second)
	kW	kilowatt (1 Watt x 10^3)
	MW	megawatt (1 Watt x 10^6)
	GW	gigawatt (1 Watt x 10^9)
	TW	terawatt (1 Watt x 10^{12})

Energy conversions

Convert to:	TJ	Gcal	Mtoe	MBtu	GWh
From:	multiply by:				
TJ	1	238.8	2.388 x 10^{-5}	947.8	0.2778
Gcal	4.1868 x 10^{-3}	1	10^{-7}	3.968	1.163 x 10^{-3}
Mtoe	4.1868 x 10^4	10^7	1	3.968 x 10^7	11 630
MBtu	1.0551 x 10^{-3}	0.252	2.52 x 10^{-8}	1	2.931 x 10^{-4}
GWh	3.6	860	8.6 x 10^{-5}	3 412	1

Currency conversions

Exchange rates (2011)	1 US Dollar equals:
Australian Dollar	0.97
British Pound	0.62
Canadian Dollar	0.99
Chinese Yuan	6.47
Euro	0.72
Indian Rupee	46.26
Japanese Yen	79.84
Korean Won	1 107.81
Russian Ruble	29.42

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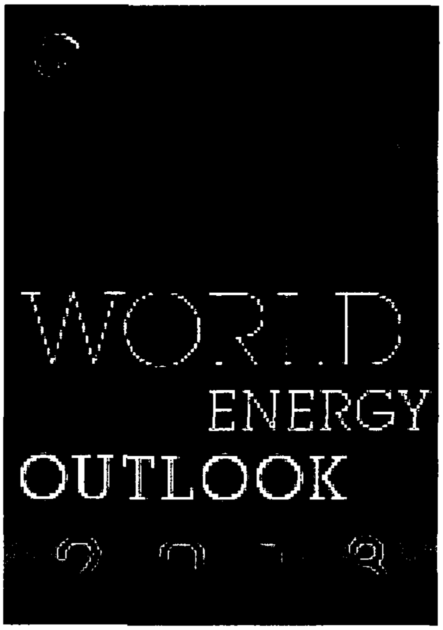

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