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CHINA’S ENERGY TECHNOLOGIES TO 2050

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Executive Summary

The future course of China's CO_2 emissions is of critical importance for climate change mitigation. These emissions have more than doubled since 2000 and, on business as usual assumptions, could represent nearly 30% of global emissions by 2050. This reflects China's status as the most populous nation on earth with a rapidly developing (largely coal-based) economy. As for other countries, climate change mitigation is only one of the objectives of China's energy policy. In addition to China's economic development objectives, energy security is a growing concern for China as its oil imports increase, and the health impacts of local air pollution remain a key political and economic issue.

This Research Report examines the pathways through which China could reduce energy related CO_2 emissions by 2050, to levels that would be broadly consistent with the global $2^{O}C$ objective. It highlights the technologies that would be required, the barriers to their deployment, and the wider implications for China's energy policy.

Can China achieve deep cuts in CO_2 emissions by 2050?

There are feasible pathways for China to significantly decarbonise its economy by 2050, using a range of commercial and pre-commercial technologies. The analysis in this report suggests that major contributors of this decarbonisation would come from:

- Power generation, where displacement of unabated coal-fired power generation (which would continue to dominate in a business-as-usual scenario to 2050) by a combination of coal and gas with carbon capture and storage (CCS), nuclear, solar photovoltaics (PV) and wind could reduce the CO_2 intensity of electricity from over 800 gCO_2/kWh to under 50 gCO_2/kWh by 2050;
- Industry, where switching to decarbonised electricity would dominate emissions savings, and where ensuring industrial plants operate at best available technology (BAT) levels and capturing industrial emissions from CCS would also be important drivers of emissions reductions;
- Transport, where about two-fifths of the savings from road transport come from electric vehicles, with the remainder from biofuels and vehicle efficiency, and where most of the remaining savings would come from efficiency improvements in rail, water and air transport, and the electrification of railways;
- Buildings, where emissions savings would depend on the widespread deployment of low carbon heating technologies such as heat pumps, the decarbonisation of

electricity in heating and lighting, and greater building shell energy efficiency.

What are the major challenges and opportunities of this transition?

The low-carbon scenarios imply significant reductions in oil and coal demand relative to business as usual, which could be highly advantageous to China given the rapid growth in its demand for these fossil fuels. The abatement scenarios would also achieve marked benefits for local air quality, with significant public health benefits. The fundamental energy system transformation implied by the low carbon scenario would cost China's economy of the order 2% of GDP by 2050. The challenges of abatement include increased demand for gas, uranium, next generation bio-energy, and the need for careful planning of water and land usage. Low-carbon policy implementation will also require close coordination with China's Provinces to account for regional diversities.

As a result of its large market and production capacity, China's low-carbon pathway is likely to have a major impact on the global development and cost reduction of key low-carbon technologies such as solar PV, electric vehicles, wind, nuclear and CCS. But China could also benefit from existing international know-how, in for example advanced nuclear manufacturing, elements of solar PV and battery technology, urban planning for transport and buildings, and monitoring and regulation of energy efficiency standards for buildings and appliances. In addition, the increasingly apparent need for a long-term, stable carbon price to support several low-carbon technologies in China points to the benefits of policies such as domestic carbon trading schemes, in which China is now looking at a range of pilot schemes.

Introduction

China's 2010 CO_2 emissions were about 9 Gt, having more than doubled since 2000[1]. Two years (2003 and 2004) saw annual increases in emissions of greater than 15%, driven by a rapid expansion of heavy industrial sectors[2]. On business as usual assumptions, these emissions are projected to continue to rise rapidly with China's continued economic development, in some scenarios representing nearly 30% of global emissions by 2050[3]. This means that the future course of China's CO_2 emissions is of critical importance for climate change mitigation.

China has recognised the need for deep cuts in emissions "with a view to reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius"[4]. However China's energy policy has multiple objectives. As explained in China's official statement to Cancun, "As a developing country with per capita GDP of only US$3,700 and ranking around 100th place globally, China still has a huge population living in poverty and is confronted with multiple challenges of economic development, poverty eradication, improving people's livelihoods and protection of climate"[5].

The security of energy supply, especially oil imports, is one of the most important energy policy objectives in China. China consumed an estimated 8.1 million barrels per day (b/d) of oil in 2009, with net oil imports of about 4.3 million b/d, making it the second-largest net oil importer in the world behind the United States, and these imports are set to increase[6]. Coal, which is the most carbon intensive fossil fuel, is also the lowest cost and most accessible source of energy in China. In 2009, coal made up 71% of China's primary energy usage, and four-fifths of electricity generation, in 2008[7]. Coal-fired power generation is set to continue its rapid growth, with some 450GW of power plants at the planning, commissioning or installation stage[8].

Fossil fuel-related air pollution has also been a major energy-related issue in China for several years. Sulphur dioxide emissions in China reached a peak of just under 26Mt in 2006, before falling back to just over 22Mt (approximately their 2004 levels) in 2009, partly as a result of the requirement for newer coal plants to fit flue-gas desulphurisation (FGD) equipment. However, a number of other pollutants such as particulate matter, nitrogen oxide and mercury remain a problem[9]. Moreover the strong growth in (oil-based) road transport in recent years has been a major source of urban air pollution from NO_X, hydrocarbons, CO and particulate matter[10].

China is aware of the need to improve its energy efficiency (its energy intensity is about 50% higher than the world average[11]) and reduce its reliance on fossil fuels, which brings not only potential economic benefits such as security of energy supplies and a reduced oil import bill, but local and global environmental benefits as well. Its 11th Five Year Plan (2006-2010) set an ambitious target to reduce energy intensity (energy consumption per unit of GDP) by 20% on 2005 levels - in the event it achieved a 19.1% reduction, but not without a degree of social and economic disruption including black-outs, the shutting down of residential heating and forced factory closures[12].

In announcing the new 12th Five Year Plan (2011-2015) the Chinese Government has signalled even more clearly a focus on sustainability and the environment. Prime Minister Wen Jiabao said, "We must not any longer sacrifice the environment for the sake of rapid growth and reckless rollouts, as that would result in unsustainable growth featuring industrial overcapacity and intensive resource consumption"[13]. The Plan contains an overall economic growth projection of 7% per year, significantly lower than actual growth in recent years. It also contains a number of energy and emissions targets including an energy intensity reduction of 16% and carbon intensity reduction of 17%, on 2010 levels. At the same time, the Plan sets out seven strategic emerging industries critical to China's economic development, including electric vehicles, energy efficient products and renewable energy. Investment in these industries will total approximately RMB 10 trillion ($1.5 trillion) over the course of the Plan (to put this figure in context, in 2010 China's GDP was about RMB 38 trillion)[14]. The Plan also includes major increases in non-fossil energy, including a four-fold growth in nuclear power to 40 GW, 63 GW of new hydroelectric capacity, 48 GW of new wind capacity and 5 GW of solar capacity by 2015[12].

China's Copenhagen Accord pledge includes a target to achieve a 40-45% reduction in carbon intensity by 2020, compared to 2005 levels, and to meet 15% of its primary energy demand from non-fossil sources by 2020[15]. Some analysis[16] suggests that China could go further, and in fact the baseline scenario assessed in this report would see it achieve the Copenhagen Accord range.

Looking beyond the 12th Five Year Plan and China's Copenhagen Accord target, there is considerable and increasing interest in China's potential long term pathways towards a low carbon economy, as part of a global effort to tackle climate change. The focus of this report is how China might achieve a significant reduction in emissions by 2050, and the implications of the scale-up in key low-carbon technologies for both China and the rest of the world.

Methodology

This study focuses on CO_2 from energy and industrial emissions. Non-CO_2 greenhouse gas (GHG) emissions and CO_2 emissions from land use are not explicitly analysed. The study uses the International Institute for Applied Systems Analysis (IIASA) Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) energy technology model to project the CO_2 emissions trajectories in China which would form part of a global least-cost GHG emissions trajectory that limits global warming to 2 degrees Celsius above pre-industrial levels. These projections have been taken from IIASA's Global Energy Assessment (GEA)[17]. The model provides a detailed analysis of the energy supply system (including electricity generation, fossil fuel extraction and conversion processes) for given levels of energy demand (split into electric and non-electric demand) in the major end-use sectors of the economy (industry, transport, residential and commercial buildings). The Grantham Institute analysis focuses on:

- analysing the implications of the low-carbon electricity generation mix in the MESSAGE model, by considering the various challenges to commercialising and scaling up the different low-carbon generation technologies;
- assessing what contribution a range of commercial and pre-commercial CO_2 mitigation technologies and measures could make to achieving the energy demand levels implied for each major end-use sector (industry, transport, buildings) in IIASA's low-carbon scenarios, based on specific models of the transport, industry and buildings sectors developed by the Grantham Institute;
- assessing the implications of these different mitigation technologies and measures on China and the international community, including the challenges to develop and deploy them, their costs, their material resource usage, and the opportunities they provide for international collaboration;
- considering the impacts of the low-carbon emissions trajectories on China's overall energy system, including its demand for fossil and non-fossil fuels, its use of land and water resources, and its energy network and infrastructure requirements.

There have been several recent studies on China's potential low carbon pathway, including:

- The China-specific analysis within the IEA's (2010) *Energy Technology Perspectives*[3];
- The Chinese Energy Research Institute (ERI)'s (2009) *Low Carbon Economy Scenario Studies up to 2050*[18];
- Sussex University/Tyndall's (2009) *China's Energy Transition – Pathways to Low Carbon Development*[19]*;*

- Lawrence Berkeley National Laboratory (LBNL)'s (2011) *China's Energy and Carbon Emissions Outlook to 2050*[20];
- Stockholm Environment Institute (SEI)'s (2011) *A deep carbon reduction scenario for China*[21]*;*
- UNDP's (2010) *China and a Sustainable Future: Towards a Low Carbon Economy and Society*[22].

This study adds to the literature by explicitly combining outputs from a least-cost optimisation model of the energy supply side (MESSAGE) with detailed models of each major energy demand sector (industry, transport, buildings) to show the full range of technologies that could be deployed as part of a low-carbon pathway. The approach links energy demand levels to underlying socio-economic drivers, which allows the use of sensitivity analysis to highlight the dependence of future emissions on variables such as electricity carbon intensity, vehicle population, building floor space and heavy industry output. Each of the other studies is referenced where relevant, to draw assumptions and comparisons between different conceptions of China's future low-carbon development pathway. Table 1 summarises some of the important features of the scenarios. They share broadly similar economic and demographic projections, but cut across a broad range of levels of CO_2 emissions in 2050. The IIASA scenarios used in this study are within this range.

Study	**IEA**	**ERI**	**SPRU/Tyndall**	**LBNL**	**SEI**	**UNDP**	**IIASA**
Abatement Scenario name	BLUE Map	Low growth, low carbon	Range (S1-S4)	Accelerated Improvement	Deep Carbon Reduction	Emissions Abatement	GEA Mix and Efficiency
Global GHG concentration limit	450ppm CO_2e	not specified	550ppm CO_2e	not specified	350ppm CO_2	not specified	450ppm CO_2e
Global warming limit, °C*	2		2.9		2		2
China 2050 emissions, $GtCO_2$	4.3	5.1	1.5-4.5^	7.4	1.9	5.5	2.2-4.5^
China 2050 emissions, tCO_2/capita	3.0	3.5	1.1-3.2	5.2	1.4	3.7	1.5-3.2
China CO_2 emissions peak year	2020	Between 2020 and 2030	2020-30^	2027	2017	2027	2020-30^
GDP average annual growth (2005-2050)	5.0%~	5.7%	4.8-5.9%	5.7%~	5.1%	5.5%	5.3%
Population (2050), billion	1.43	1.46	1.40	1.41	1.41	1.41	1.42
Urbanisation (2050), % of population	78%$^{+}$	79%	not specified	79%	79%	70%	70%

Table 1: Selected studies on China's low-carbon transition pathway to 2050

Notes: * at least a 50/50 of limiting warming to this level as specified by the study; ^ depends on scenario; $^{\sim}$ IEA data for 2007-2050, LBNL for 2010-2050. Figure for 2005-2050 calculated using outturn 2005-2010 growth rates; $^{+}$ IEA only gives urban household share which is shown here.

China's emissions reduction trajectory

The IIASA MESSAGE model used for this study calculates the least-cost mix of technologies that would deliver a given level of energy demand, within a specified emissions limit. The model assigns emissions reductions to the regions of the world in which they would occur at least cost. The implications of these scenarios for burden sharing of emissions targets would, of course, also depend on the extent to which emissions reductions in less developed countries were funded by other regions (as would be the case with carbon market mechanisms such as the CDM, for example).

The model in its current form lacks sufficient geographical detail to model China on its own, instead modelling a "Central and Planned Asia" (CPA) region, of which China makes up about 90% of both GDP and population across the period 2010-2050 (the rest of the Central and Planned Asia region is made up of Cambodia, North Korea, Vietnam, Mongolia and Laos). This study analyses three IIASA emissions scenarios for the CPA region, as developed for IIASA's Global Energy Assessment (GEA)[17]:

- a "Baseline" scenario with no emissions limit;
- an "Efficiency" abatement scenario which emphasises demand side energy efficiency improvements, resulting in developing country energy intensity reductions of over 3% per year compared to average reductions of less than 2% per year since 1970. In addition, the Efficiency scenario assumes a very low emissions floor can be achieved after 2050, resulting in a less aggressive reduction in emissions by 2050;
- a "Mix" abatement scenario with lower demand side energy efficiency improvements, a diverse mix of low-carbon energy supply technologies, and a more aggressive emissions reduction by 2050 compared to the Efficiency scenario. The Mix scenario allows emissions to peak at a slightly higher level than the Efficiency scenario.

Both the Mix and Efficiency abatement scenarios are part of global emissions scenarios which are aimed at limiting global warming to 2 degrees Celsius above pre-industrial levels (depending on assumptions about climate sensitivity)[23]. Figure 1 shows the three scenarios' emissions trajectories compared to each-other, and to selected emissions trajectories from a selection of other recent studies on China's pathway to 2050.

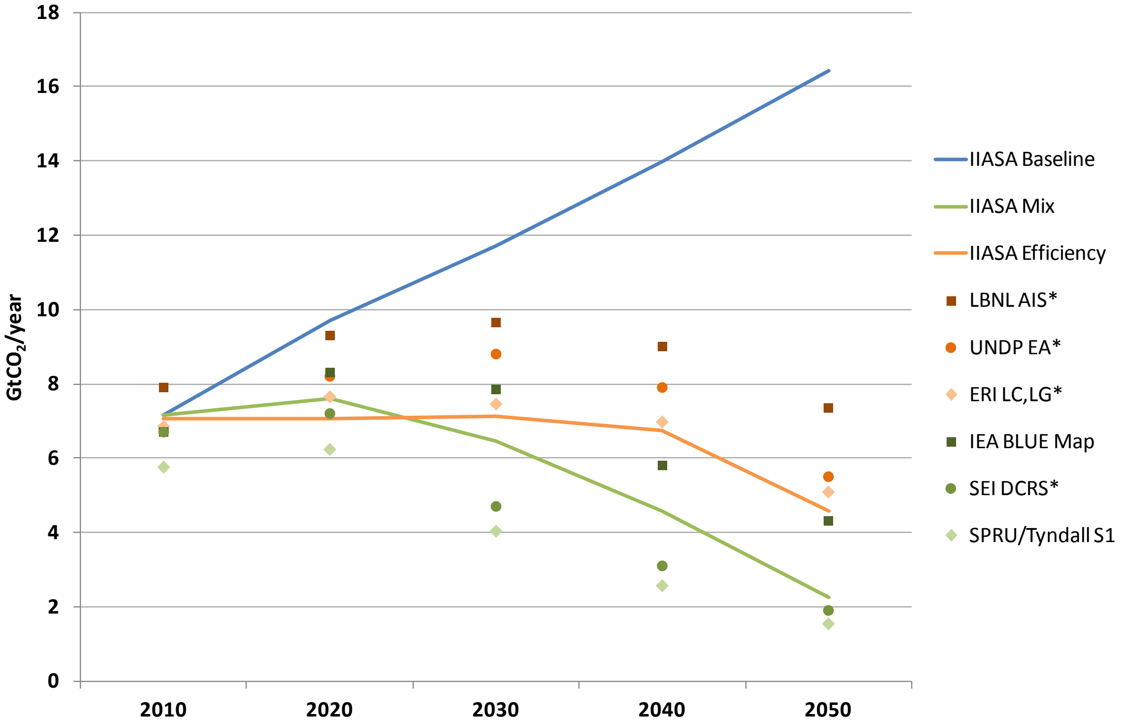

Figure 1: CO_2 emissions trajectories for IIASA and other scenarios

Notes: *AIS = Accelerated Improvement Scenario; EA = Enhanced Abatement; LC, LG = Low Carbon, Low Growth; DCRS = Deep Carbon Reduction Scenario.
SPRU/Tyndall S1 is the most stringent of the four scenarios examined in this study.
All scenarios are for China, except IIASA which are for the Central and Planned Asia (CPA) region.
Figures for other studies are approximated from published charts and not always based on underlying data.
References to, and further details on, all studies are the in “Methodology” section of this report.

Figure 1 shows that the baseline CO_2 emissions continue to grow to about 16 $GtCO_2$ by 2050. In contrast emissions peak in 2020 in the Mix scenario and remain at a fairly flat level between 2010 and 2030 in the Efficiency scenario, before falling at an increasing rate to below 3 $GtCO_2$ (Mix) and below 5 $GtCO_2$ (Efficiency) by 2050. The Figure locates these scenarios within those of other studies, which together provide a broad range of possible pathways depending on the stringency of action. The IIASA Efficiency pathway appears to be well within this range, although the IIASA Mix scenario is towards the low end, particularly considering that the IIASA scenarios are for “Central and Planned Asia”, some 10% larger than China alone. It should be noted that there is already a discrepancy between the 2010 figures, which are essentially projections from earlier points of calibration for these models, and the preliminary 2010 outturn figures for China, which could be close to 9 $GtCO_2$ in 2010[1].

Assuming China’s Copenhagen Accord pledge of a 40-45% carbon intensity reduction on 2005 levels by 2020 were applied to the CPA region as a whole, the baseline scenario would achieve the mid-point of the range presented in the pledge, which reflects that even the baseline assumes significant improvements in energy and carbon intensity. The Efficiency scenario would achieve a 54% reduction in carbon intensity and the Mix scenario a 58% reduction in carbon intensity, relative to 2005 levels. In other words, China's stated ambitions for carbon reductions to 2020 appear more consistent with the baseline than with the abatement scenarios. This does not alter the message of the Mix and Efficiency scenarios that dramatic reductions in CO_2 emissions are achievable over the longer term, but it underlines the need for early action if these reductions are to be achieved. The Grantham Institute's own modelling, described later in this report, suggests that provided key low-carbon technologies penetrate through the different sectors of the Chinese economy, the rates of emissions reductions to 2050 suggested by the more aggressive Mix scenario are feasible.

These intensity targets are calculated on the basis of annual GDP growth of 7.1% in the decade 2010-2020 – broadly in line with China's 12th Five Year Plan target of 7% per year, although the 11th Five Year Plan target (7.5% per year) was significantly exceeded, with annual growth closer to 10% per year[12]. Higher economic growth to 2020, without correspondingly higher growth in CO_2 emissions (as may be the case with a shift to lower carbon energy sources and away from the most carbon-intensive industry), would lower the region's carbon intensity by 2020.

Both the Mix and Efficiency scenarios result in significant reductions in overall fossil fuel dependence, as shown in Figure 2. By 2020, non-fossil sources would make up 10% of total primary energy in the baseline scenario, compared to 15% in the Mix and 14% in the Efficiency scenarios. This can be compared to China's Copenhagen Accord pledge to source 15% of primary energy from non-fossil sources by 2020[15]. There is a significant reduction in coal demand from 2020 in both abatement scenarios, whereas in the baseline scenario coal demand continues to increase throughout the period to 2050. By 2050 coal demand in the abatement scenarios is about a quarter of the baseline scenario. In the Mix scenario oil demand continues to grow to 2030, and then declines to 2050, compared to a continued increase in the baseline scenario. The Efficiency scenario sees oil demand grow more slowly to a similar level to the Mix scenario in 2040, before declining to 2050 more slowly than the level in the Mix scenario.

The most important factor in reducing coal and oil demand is energy efficiency and conservation, which in the Mix scenario reduces energy demand to just over half the level in the baseline scenario by 2050. The other principal drivers of reduced coal and oil dependence in both abatement scenarios are (respectively) a marked increase in non-fossil power generation and the increasing electrification of, and use of bio-energy in, the transport sector.

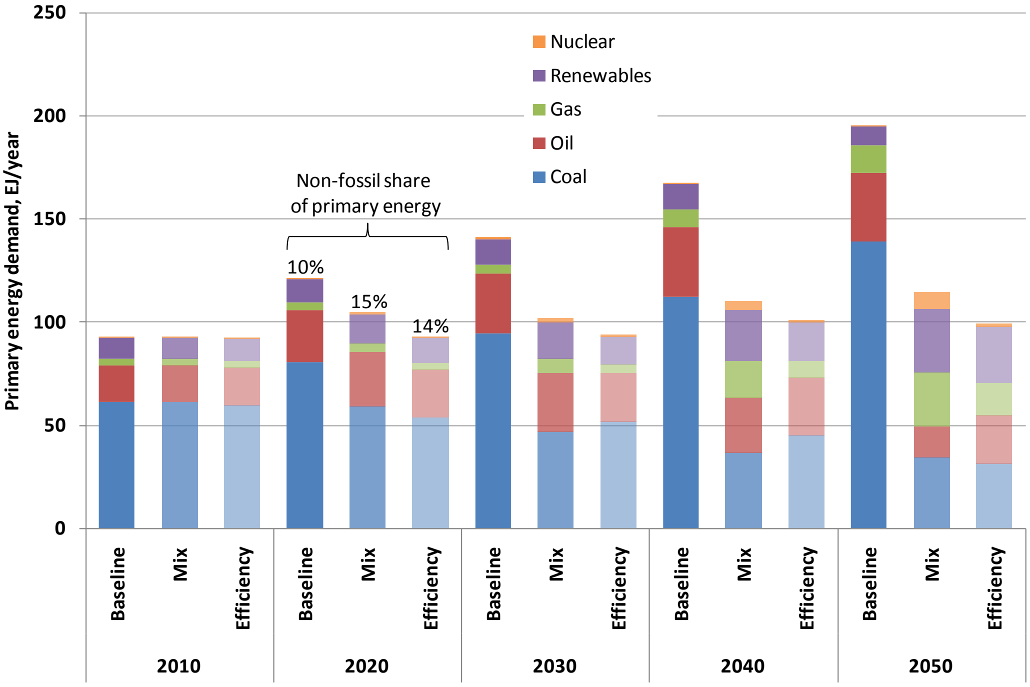

Figure 2: CPA primary energy demand in the IIASA baseline and abatement scenarios

As well as reduced dependence on fossil fuels, the abatement scenarios show a reduction in all major local air pollutants. Levels of two of the most damaging to health, sulphur dioxide (SO_2) and particulate matter (PM2.5) are shown in Figure 3. Levels of these pollutants fall even in the baseline scenario, despite increased use of fossil fuels over time, as the scenario assumes that World Health Organisation recommended limits to local pollution are enforced. However, effective abatement of indoor and outdoor air pollution are specific objectives of the IIASA abatement scenarios, which lead to further reductions in these levels of pollutants – to less than half the levels in the baseline scenario by 2050.

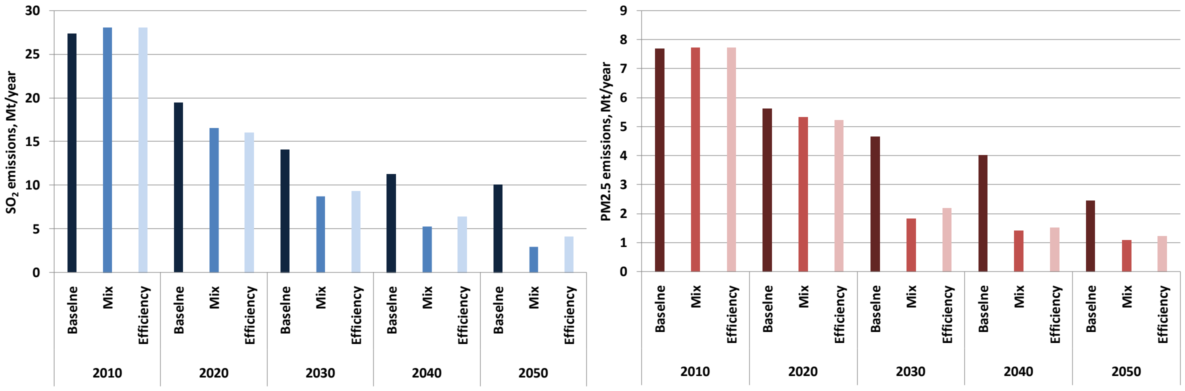

Figure 3: CPA SO_2 and PM2.5 levels in the IIASA baseline and abatement scenarios

Consumption losses in the CPA region in the Mix scenario are about 2% of GDP in 2050, relative to the baseline. This would need to be compared against a projected growth in consumption of about 500% in the CPA region over the period to 2050. This figure is derived from the MESSAGE modelling alone, whose focus is more on the energy supply technologies (i.e. electricity generation and other energy conversion). The modelling accounts for the economic benefits of reducing energy usage as a result of the uptake of energy efficiency technologies, but it does not take full account of the costs of investments in and operation of low-carbon demand-side technologies such as low-carbon electric vehicles, for example. As such, it could be an underestimate of the total cost to the Chinese economy. On the other hand, this cost does not state the share of costs met within China and the share met through foreign finance, through mechanisms such as the CDM, for example.

The following sections of this study analyse in detail where the major emissions savings come from in the abatement scenarios relative to the baseline scenario, and the challenges to scaling up low-carbon technologies to the degree required to make these emissions savings. They also consider the challenges that the baseline scenario itself would pose, mainly in terms of fossil fuel supplies, energy security and pollution.

Power sector

The IIASA Mix scenario has a similar electricity demand to the baseline scenario by 2050 as shown in Figure 4, as a result of increased electrification in the economy broadly offsetting energy demand reductions. However, the installed capacity is much higher than in the baseline, as renewable sources with lower average load factors, such as solar PV and wind, are built in place of coal-fired generation plant, which has a much higher average load factor. The Efficiency scenario has about 20% less electricity demand than the baseline and Mix scenarios, as a result of greater energy efficiency measures, which more than offset the increased electrification.

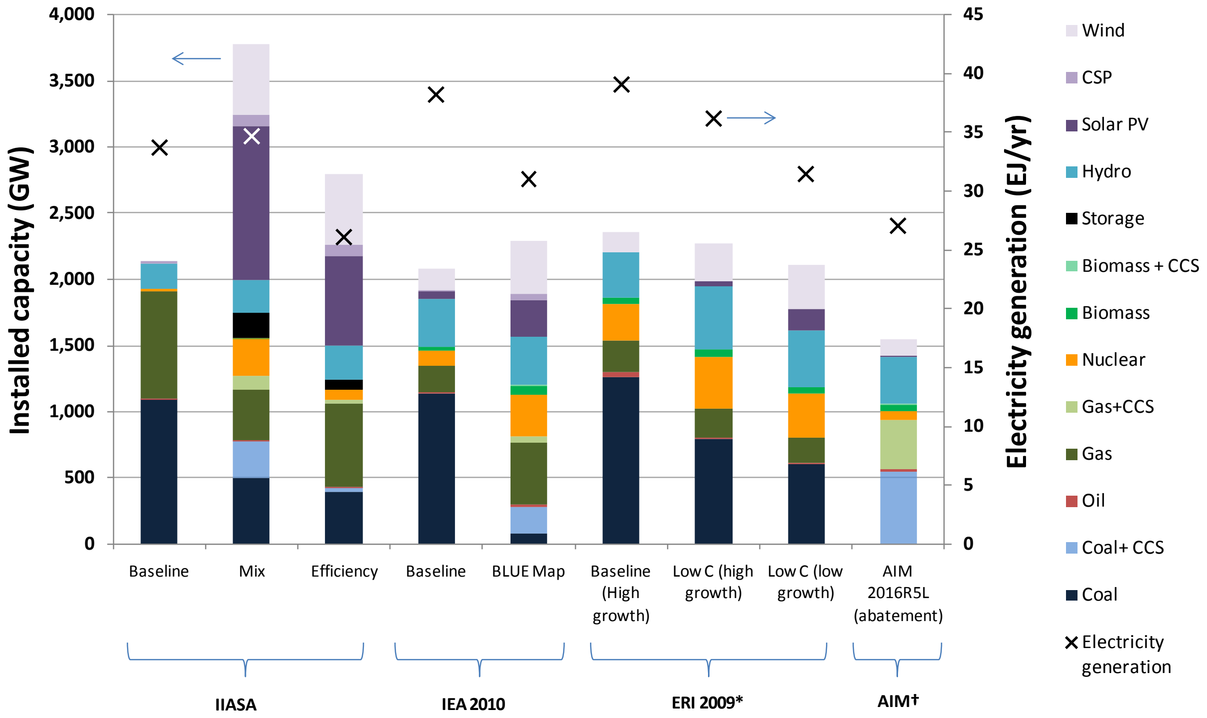

Figure 4: 2050 CPA electricity generation and capacity mix in IIASA baseline and abatement scenarios, with other model outputs included for comparison

Notes: *ERI does not specify CCS or differentiate between solar PV and solar CSP.
[†]AIM GW values calculated from energy values using IIASA Mix annual capacity factors. AIM modelling undertaken as part of AVOID[24] assessment of global low-carbon pathways.
Blue arrows show axes to which crosses and bars refer.

Whilst the IIASA MESSAGE model accounts for the lower load factors in variable renewable generation technologies, it is unclear the extent to which a radical increase in the use of smart grid technology, to better match the electricity supplied from variable renewable sources to demand, could decrease the required level of installed capacity. Specific spatial and temporal modelling of demand and supply in electricity networks would be beneficial in understanding the potential for this further, not just in China but in all regions that could see increased renewable penetrations. For example, a recent study[25] on the European power system suggests that, by 2030 when the penetration of variable generation sources will have increased significantly, achieving a 10% shift in electricity demand from peak times to non-peak times through smart technologies could reduce grid capacity by 10% and back-up capacity by 35%, saving significant investment costs and reducing the volatility of power prices.

It could be challenging for China to reduce the amount of non-CCS coal-fired generation capacity to the levels resulting from the abatement scenarios, given that so much new non-CCS coal plant is due to start generating in the next few years (as discussed in Section 1, reportedly 450 GW, with 260 GW in the 12th Five Year Plan period alone). Much of this plant would have to be retrofitted with CCS equipment, or retired before 2050, indicating plant lifetimes of less than 40 years.

Figure 5 shows the electricity generated by technology type for each of the three IIASA scenarios, in 2050. This demonstrates that, in spite of the large capacity of gas plant in the baseline scenario, the majority of generation is coal-fired. By contrast, in the Mix scenario there is little remaining coal generation (in spite of a large installed capacity, much of which by 2050 is due for imminent retirement), with the majority of generated electricity from coal with CCS, nuclear, hydro, solar PV and wind - all zero or very low-carbon technologies. This results in a CO_2 intensity of electricity generation of less than 50 g/kWh, compared to 750 g/kWh in the baseline scenario. In the Efficiency scenario, which has lower electricity demand than the Mix scenario, and which also has a higher level of overall emissions in 2050, electricity CO_2 intensity is about 280 g/kWh, with non-CCS coal still the largest contributor to generation.

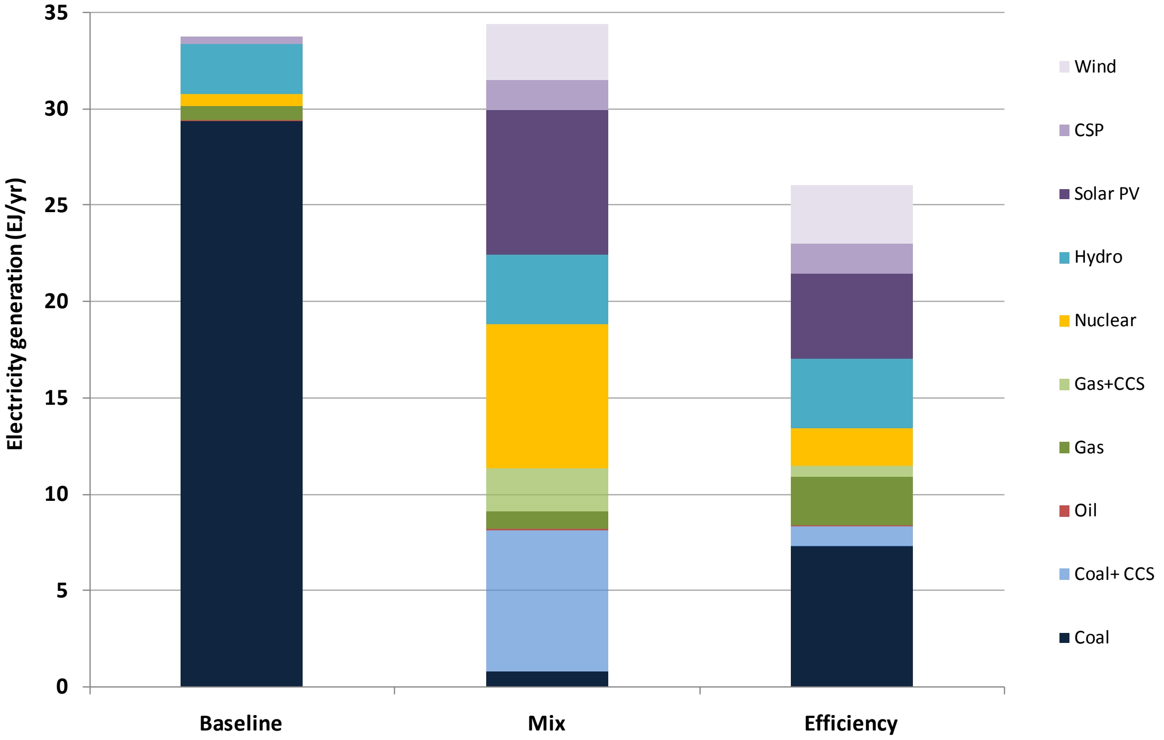

Figure 5: 2050 CPA electricity generation by technology in the IIASA scenarios

It should be noted that switching from coal to gas-fired generation, which occurs in all three IIASA scenarios, is somewhat speculative given that there are significant uncertainties over the future availability of gas resources in China (both conventional and unconventional, as discussed later), and the extent to which these would be prioritised for use in different sectors of the economy (e.g. in home heating, industrial usage, or electricity generation). Some caution should therefore be given to the possibility of a large shift from coal to gas generation.

The power generation mixes in the IIASA scenarios are determined by a consideration of the relative costs of the different generation technologies and how these could develop in the future. Figure 6 compares the IIASA levelised costs with ranges of estimates derived from the literature. This shows that IIASA are relatively optimistic about the cost reductions possible for solar PV, wind and nuclear, but actually less optimistic about costs of coal and coal with CCS. The Grantham Institute's own analysis suggests that there could be barriers to the continued cost reductions of solar PV, and that the lower end of the IIASA cost range by 2050 is possibly too optimistic, especially when compared to the fossil-fuel technologies and estimates from other studies. This leads to a deployment of solar PV in both IIASA abatement scenarios which is much higher than those in comparable studies, whilst by contrast, nuclear and hydro are relatively under-deployed compared to other studies (see Figure 4 for some comparative studies).

Hydro, in particular, is likely to be deployed to a greater extent than indicated in the IIASA scenarios, which in both the Mix and Efficiency cases show only 250 GW of capacity by 2050. China already has 200 GW of hydro, and has a 2020 target to deploy 380 GW of hydro[7], though, as discussed in the Cross-cutting issues section of this report, hydro is by far the largest consumer of water and its viability could be limited in water-stressed areas. As concerns nuclear, there remain considerable uncertainties in the wake of the March 2011 Fukushima incident around the future speed and level of deployment of the technology in China, but recent statements have indicated that plans to 2020 and beyond may not be very greatly affected[26]. This aside, a number of studies have projected a considerable deployment of nuclear by 2050. For example The IEA's BLUE Map scenario has 318 GW of nuclear by 2050, whilst China's ERI Low Carbon scenarios have a range of 337 - 388 GW by 2050, as shown in Figure 4. This compares to nuclear deployment of about 11 GW in 2010[27].

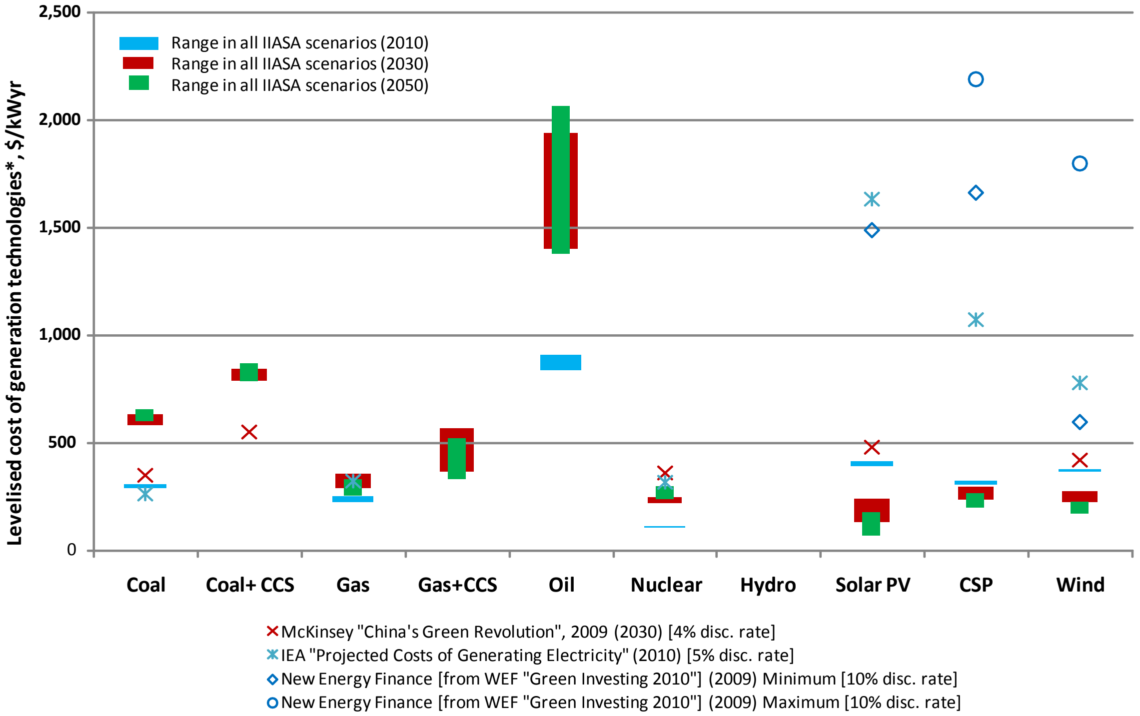

Figure 6: Levelised cost comparison for low-carbon generation technologies

Notes: *Year of applicability in brackets; IIASA values calculated using a 5% discount rate; New Energy Finance gives a 'maximum' value for Solar PV of $3945/kWyr, not shown here; Biomass not included due to the uncertainty in fuel prices; CCS does not include transportation and storage, but includes an efficiency de-rating and the additional investment and operating costs. Uranium fuel cycle costs are not included here, but can be expected to account for 10-30% of the total electricity cost [28,29]. Data sourced from McKinsey 2009 [30], IEA 2010 [28] , NEF 2010 [31].

Levelised cost estimates are only a partial guide to the likely mix of investments made in reality, given that a number of factors drive actual investments. These include social factors such as the need to respond to public concerns over safety (such as nuclear in Germany) or protection of the landscape (such as onshore wind in the UK), political targets such as the EU's 2020 renewable energy targets, and financial considerations such as the riskiness of new technologies (e.g. CCS).

There will be a number of challenges involved in scaling up each of the major low-carbon power generation technologies in the abatement scenarios, as shown in Table 2, based on the views of technology experts at Imperial College. Continued investment in R&D to bring down the costs of solar PV and to commercialise CCS will be critical factors to achieving the large penetrations of these technologies. Continued support for wind power will also be essential to ensure its deployment. Nuclear could also be a key technology, requiring careful consideration of access to uranium supplies, through either more efficient fast-breeder reactors or alternative (thorium) fuel reactors. In addition, the changing climate and its effect on rainfall and water availability will be considerations for a number of power technologies, especially hydro power. One of the greatest challenges in providing decarbonised electricity will be in balancing the system to ensure that supply meets demand, as responsive generation plant such as coal-fired plant (whose output can be varied relatively quickly in response to demand variation) is replaced by variable output renewables (wind, solar), or nuclear which is currently best suited to base load generation. China's wind, solar, and hydro resources are highly dispersed geographically, and the development of a strong long distance grid will be essential to exploit them fully.

The investment required to scale-up many of the low-carbon generation technologies in the short and medium term, and the use of CCS in the long-term, points to the need for specific policy interventions including a stable, long-term mechanism for the pricing of carbon. In fact China is already planning to launch a number of pilot emissions trading schemes[32].

Technology	2050 capacity (GW)	Status of technology in China/abroad	Key challenges to scale-up to 2050 levels
Solar	PV 1,200, CSP 90 (Mix); PV 700, CSP 90 (Efficiency)	• Silicon solar photovoltaic (PV) is a mature, proven technology. • China is currently the largest producer of solar PV cells. The largest user at present is Germany, with Spain, Italy, the US and Japan significant users. • Concentrated Solar Power (CSP) – already over 1 GW installed globally.	• For silicon PV, cost reduction is still a key challenge, through integration of production processes such as Si purification and wafer manufacture; • The embedded energy and carbon of silicon PV is significant compared with other renewable technologies. Newer technologies e.g. thin-film PV are likely to improve this; • Water is a constraint for CSP. The success of closed-cycle or air-cooled CSP plants will be critical for the growth of CSP; • Distributed solar PV and variable output for both solar PV and CSP will require careful integration of a long-distance grid.
Nuclear	290 (Mix) 80 (Efficiency)	• Chinese domestic technology is currently Generation II and II+; • Currently importing foreign Generation III technologies, but likely to have the capacity to develop own Generation III by 2020; • Nuclear capacity at present in China is modest, at less than 10 GW up to 2010, but there is an ambitious target of 70 GW installed in total by 2020.	• Manufacturing of certain specialised parts (e.g. the pressure vessel, large pumps and valves) is only done by a small number of companies world-wide; • China will rely heavily on uranium imports in 2050. Use of thorium, enhanced fuel reprocessing and fast-breeder reactors would relax this constraint significantly; • Development of load-following capabilities (e.g. Light water reactors) is challenging; • Following the events in Fukushima in March 2011, safety and public acceptance will be critical.
Wind	530 (Mix) 530 (Efficiency)	• China's wind market is relatively new, but already the largest in the world with over 42 GW installed by 2010; • Recent announcements from China specify offshore wind as an important area for growth in the near future [33].	• Grid connectivity is a key bottleneck at present, which needs to be addressed as scale-up increases; • Development of a domestic capability in large turbine technology is a key challenge - relatively small number of technical experts.
Hydro	250 (Mix) 250 (Efficiency)	• China has a number of large hydro plants as well as many smaller plants. These total nearly 200 GW as of 2010.	• Geographical separation of resource and demand requires a long-distance transmission network; • Delays and increased costs due to environmental risk and population displacement are a major barrier for hydro – careful planning will be required.
Integrated Gasification Combined Cycle (IGCC)	110 (Mix) 10 (Efficiency)	• Known technology but relatively few fully operational plants in the world; • Still an immature technology in China – plans are underway to construct a IGCC demonstration plant.	• Uncertainty in the cost of IGCC; • Requires additional steps such as gasification and air separation which carry an efficiency penalty particularly with lower quality coals.
CCS	Coal 290, Gas 90 (Mix) Coal 40, Gas 30 (Efficiency)	• Urgent need for 'large-scale integrated projects' (LSIPs); Currently nine LSIPs in operation worldwide; • Pulverised coal and IGCC pilot plants under development in China, with investigation into enhanced oil recovery potential; • Estimated onshore CO_2 storage capacity in China is 2300 Gt – 91% of large plants are within 100 miles of storage.	• High cost and technical uncertainty; • Increase water and fuel consumption (due to efficiency penalty) will place increased strain on China's scarce water resources and speed up the depletion of China's coal reserves; • Technology 'lock-in' as new plants are built – cost of retrofitting plants for CCS is higher.

Table 2: Challenges to scaling up the key low carbon power generation technologies in China

Industry

Total final energy consumption in industry accounted in 2007 for more than two-thirds of total Chinese energy consumption[9]. China significantly increased its energy intensive industrial output during 2003 and 2004, particularly in iron and steel and cement, which together made up 77% of all industry CO_2 emissions in 2007[3]. This increase reoccurred in 2010, with steel and cement production up 10% and 15% respectively, on 2009 levels, partly as a result of China's economic stimulus package which included investment in transport infrastructure and rebuilding Sichuan communities after the 2008 earthquake[1].

Looking forward, industry's share of economic output is expected to decline over the coming decades[18], as China's economic structure shifts towards less energy-intensive manufacturing and service sectors. Given the size of industrial emissions, the rate at which this shift occurs will be critical to determining the overall emissions – and emissions reduction potential – in China. Where China's energy-intensive manufacturing share declines because it shifts to other countries and regions, this would not necessarily result in a reduction in global emissions.

IIASA's Baseline scenario projects emissions from industry (including indirect emissions from electricity usage) will be 7.3 $GtCO_2$ in the CPA region by 2050, about 45% of total CO_2 emissions in the region. By contrast, industry is projected to emit 0.7 (Mix) - 2.0 (Efficiency) $GtCO_2$ in 2050 in the IIASA abatement scenarios, 29% of total CO_2 emissions in the Mix scenario and 42% in the Efficiency scenario by 2050.

IIASA uses aggregated assumptions on the trends in energy demand (split by energy type) in the industry sector. In order to assess the specific abatement options which would achieve an emissions reduction broadly in line with IIASA's scenarios, the Grantham Institute has developed a bottom-up model of the industry sector in China, examining the potential for reductions in energy intensity, fuel switching to lower carbon fuels, and CCS in industry sectors. The key assumptions are:

- Industry is divided into 8 subsectors: iron and steel, chemical and petrochemical, non-ferrous metals, non-metallic minerals (largely cement), machinery and transport, food and tobacco, pulp and paper and other (including construction and textiles);
- Total energy demand by sector is determined from projections of production rates and improvements in energy intensity. Adoption of Best Available Technology (BAT) and efficiency improvements in the iron and steel and cement sectors are modelled in detail including penetration of electric arc furnaces in the iron and steel sector and advanced New Suspension Preheater (NSP) kilns in cement. Carbon capture and storage is

modelled for the iron and steel and cement sectors, accounting for the increase in energy intensity due to added energy requirements for capture;

- Total emissions are determined from fuel shares and the emissions factors of each fuel type. Estimates of how the fuel share for each sector would change are made using the 2005 fuel mixes of other industrialised countries (e.g. United States, Korea, Germany and Australia);
- Electricity CO_2 intensity is taken from the IIASA Mix scenario.

Figure 7 shows the resulting emissions (direct, process and indirect) in each of the abatement scenarios. The Grantham Institute scenario shows higher emissions than both IIASA abatement scenarios to 2020 but thereafter declines to a level between the IIASA Mix and Efficiency scenarios, decreasing to 1.5 $GtCO_2$ in 2050. This is about 40% lower than the emissions projected by the IEA BLUE Map scenario of 2.6 $GtCO_2$ in 2050, due its higher assumed emissions factor of the electricity sector of 121 gCO_2/kWh by 2050. The large emissions reduction observed in the IIASA Mix scenario is due to a combination of fuel switching away from coal and combined with almost complete decarbonisation of the power sector, reaching an emissions factor of below 50 gCO_2/kWh by 2050.

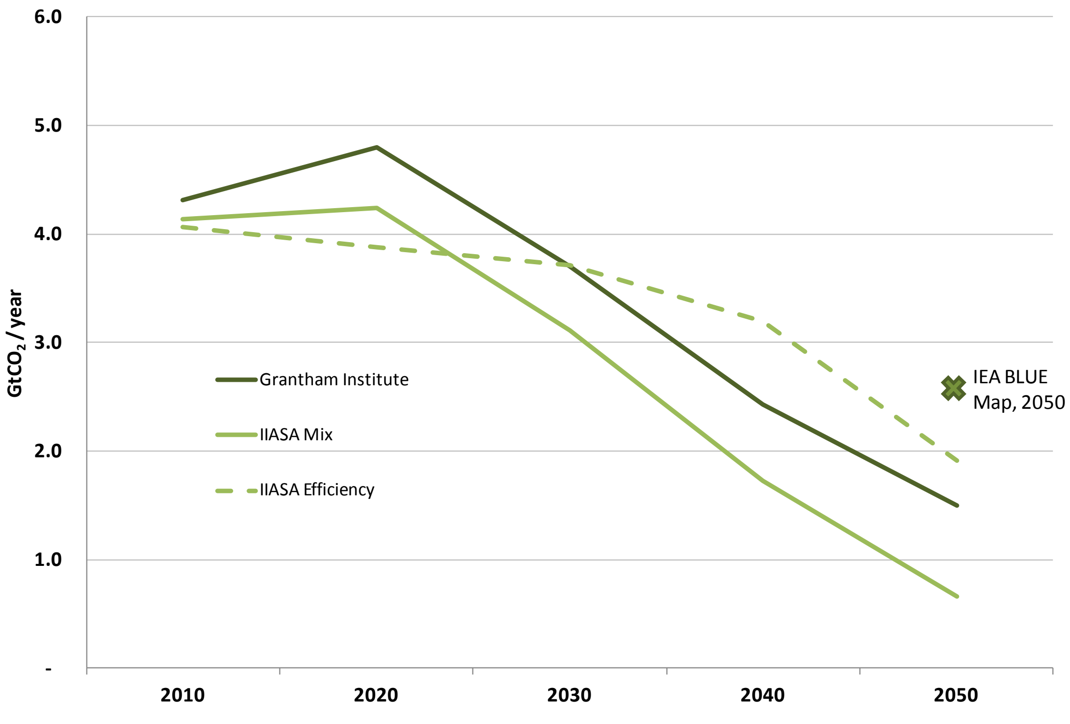

Figure 7: Industry emissions in Grantham Institute and IIASA abatement scenarios

Figure 8 shows a breakdown of the emissions savings in the industrial sector for China in 2050 in the Grantham Institute abatement scenario. Owing to the significant contribution of iron and steel and non-metallic minerals (largely cement) manufacturing to overall emissions, the figure also shows the share of savings from these sectors. Switching to decarbonised electricity results in the largest emissions savings. This is a result of using the electricity CO_2 intensity in IIASA's Mix scenario, where by 2050 electricity is highly decarbonised, as described above.

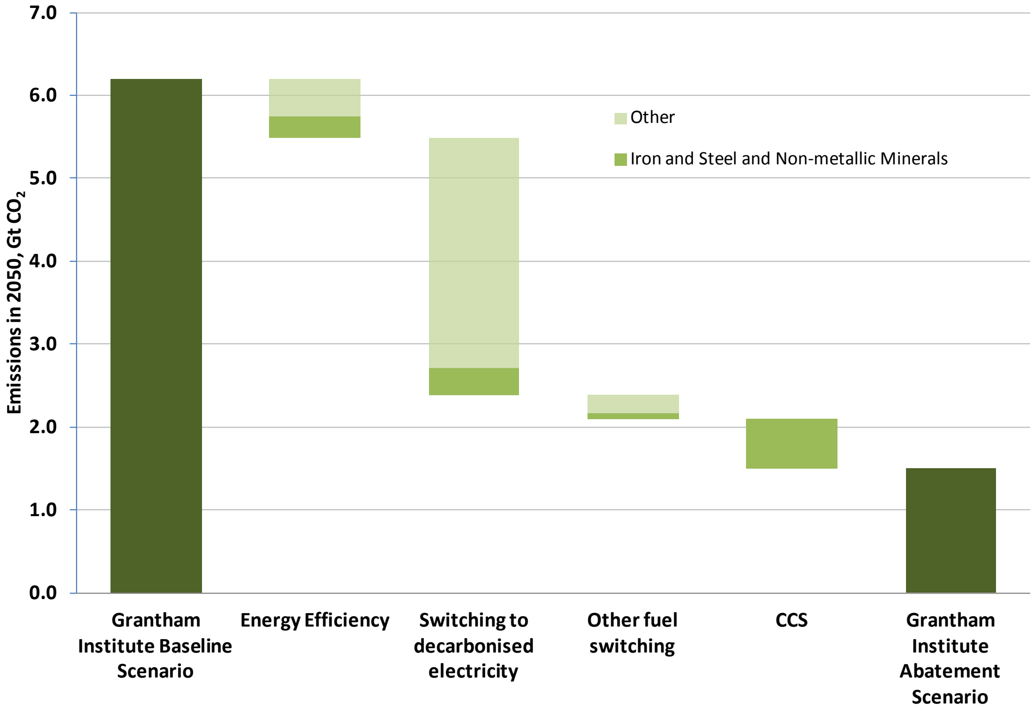

Figure 8: 2050 industry emissions savings in Grantham Institute abatement scenario

A significant share of emissions savings in the Grantham Institute abatement scenario could be achieved at low or negative costs, as shown in Table 3. However, these savings, based on the achievement of energy efficiency through adopting best available technologies (BAT) such as those in the 11th Five Year Plan's energy efficiency policies, highlight the difficulty for the Chinese Government to implement policies to lower energy and emissions. Whilst at a high level the policies have been successful in reducing energy intensity, there have been reports of social and economic disruptions, and in some cases only temporary closures of smaller, less efficient steel plants which then reopened to meet China's surging demand[34].

The largest element of emissions savings is linked to the decarbonisation of electricity. There will be several challenges to scaling up the requisite technologies and measures, also shown in Table 3. In addition, CCS for industry, which could make a sizeable contribution to overall industrial emissions savings, is still not a commercially demonstrated technology, and its potential cost means that it is likely to require targeted support in the early stages of its development, and some form of long term, stable carbon price to ensure it is economic for industry to commercially deploy it. The development and commercial demonstration of industry CCS is an urgent priority for the international community to realise this important abatement option.

Technology	2050 abate-ment potential (Gt CO_2)	Abatement cost range*	Status of technology in China/abroad	Key challenges to scale-up to 2050 levels
Best available technology (BAT) and energy efficiency	0.71	Negative to low	• While some efficient, new plants with BAT exist in China, most of the Industrial sector is highly disaggregated with a large number of small, inefficient plants. The efficiency gap of these plants is large, and recent policies have sought to close down many of these (e.g. Top 1000 industries Programme[35]).	• Potential for further consolidation in energy-intensive sectors (to accelerate the spread of BAT) in new plants is becoming limited; • Local iron ore and bauxite is lower quality which limits efficiency improvements; • High quality coal for coking will compete with other uses (e.g. In power); • Some of the BATs need gas as fuel, for which availability is limited in China.
Switching to decarbonised electricity	3.10	Medium	• The share of electricity in industry in China is low (24% in 2005 compared to an OECD average of 31%[36]). • In the steel industry, the share of Electric Arc Furnace steel production in China is around 15% - limited by availability of scrap, which is currently imported[37].	• In the steel industry, scrap availability is a key limitation. It is uncertain whether China will be able to increase steel recycling to levels of developed countries (~30%) in this timeframe, which would be required to meet scrap demand[38].
Switching to other less carbon - intensive fuels	0.28		• Over 20 yrs experience of biomass/waste co-firing in cement kilns worldwide. Leading countries are Netherlands (Substitution rate of 83%) and Switzerland (48%); • Biomass co-firing in China is currently low. The potential for biomass/waste co-firing in China is good – owing to widespread availability and underutilisation of biomass residues/wastes; • 70% of world Ammonia production is from natural gas (cf 20% in China); • Biomass CHP in pulp and paper industry is widely used in developed countries	• Uptake of biomass substitution depends on a distribution network – relies on geographical proximity of fuel sources to manufacturing plants; • High prices and limited natural gas reserves will limit Ammonia production from gas. Moreover, gas usage might be prioritised for usage in the power sector (as backup capacity) or in buildings (to increase air quality).
CCS in industry	0.60	High	• China's estimated viable storage capacity is about 2000 Gt; • The application of CCS to industry is still in the research/early demonstration phase; • Carbonate looping is a promising technology for capture from cement plants (e.g. Cemex has a pilot plant in Monterrey, Mexico) • Oxy-fuel combustion has been demonstrated in the steel industry, and the related oxy-coal combustion method is currently being demonstrated	• Lack of data and research in the application of CCS to industrial processes such as cement or iron and steel. • High uncertainty in the costs and emissions reduction potential. Highly dependent on early demonstration of feasibility • Most cement plants will need to be retrofitted, since cement production is expected to peak by 2020 • Iron and Steel production is estimated to peak around 2030. Since CCS retrofit of steel plants is difficult, early rollout of CCS-ready plants is crucial

Table 3: Summary of abatement options in the Chinese industry sector

Notes: *Low Cost = \$0-50/tCO_2; Medium Cost = \$50-100/tCO_2; High Cost = over \$100/tCO_2, using judgements based on a range of sources[30] [39] [40] [41] [42]

Transport

Transport accounted for 7% of total Chinese CO_2 emissions from fossil fuels in 2008[2], with emissions from this sector having grown almost five-fold since 1990[6]. This has been largely a result of rapid growth of road vehicles – in 2007 there were about 45 million vehicles on the road, about three times the number in 2000 and about eight times the number in 1990. Passenger vehicles are a major component of this growth, with annual growth rates above 20% in recent years. With increasing incomes it is expected that this growth will continue – how quickly is uncertain and a major area of sensitivity in transport emissions projections.

IIASA's baseline scenario projects emissions from transport to be 2.3 $GtCO_2$ in the CPA region by 2050, about 14% of total CO_2 emissions in the region. Due to rapid growth of this sector, it is projected that transport (including direct emissions and indirect emissions from electricity) will emit 0.8 (Mix) - 1.1 (Efficiency) $GtCO_2$ in 2050 in the IIASA abatement scenarios, 37% of total CO_2 emissions in the Mix scenario and 24% in the Efficiency scenario by 2050.

In order to assess the specific abatement options which would achieve an emissions reduction broadly in line with IIASA's scenarios (which specify energy demand and energy mix levels, but not the specific low-carbon technologies that would drive these), the Grantham Institute has developed a bottom-up model of the transport sector in China, examining the potential for low-carbon fuels (principally increasingly decarbonised electricity and biofuels) and energy efficiency in the transport sectors. The key assumptions are as follows:

- **Road transport:** The vehicle population in China increases to 320 million by 2050, in line with assumptions made by IIASA. Electric vehicles increasingly penetrate the market, with sales of electric vehicles accounting for 40% of new vehicle sales by 2050; By 2050, hybrid vehicles (all variants including mild, full and plug-in) account for the remainder of sales; biofuels consumption reaches 70 million tons of oil equivalent by 2050[43];
- **Non-road transport:** Rail is fully electrified by 2030, with a one third improvement in energy efficiency by 2050 compared to 2010; biofuels increase their share of air transport fuel to 20% and of marine transport fuel to 30% (compared to IEA BLUE Map assumptions of a biofuel share of 30% for both air and marine transport by 2050);
- **Electricity:** the carbon intensity is assumed to be that of the IIASA Mix abatement scenario.

Figure 9 shows the resulting emissions in each of the abatement scenarios. The Grantham Institute's abatement scenario shows higher emissions than both of IIASA's abatement scenarios to 2020, but peaks in 2030 and falls to a level between the IIASA Mix and IIASA Efficiency scenario by 2050. Emissions for both IIASA abatement scenarios peak in 2040. The IEA BLUE Map figures have been included for order of magnitude comparison purposes only, as they include full well-to-wheel emissions levels, as opposed to emissions directly from final energy usage in transport as in the Grantham Institute and IIASA scenarios.

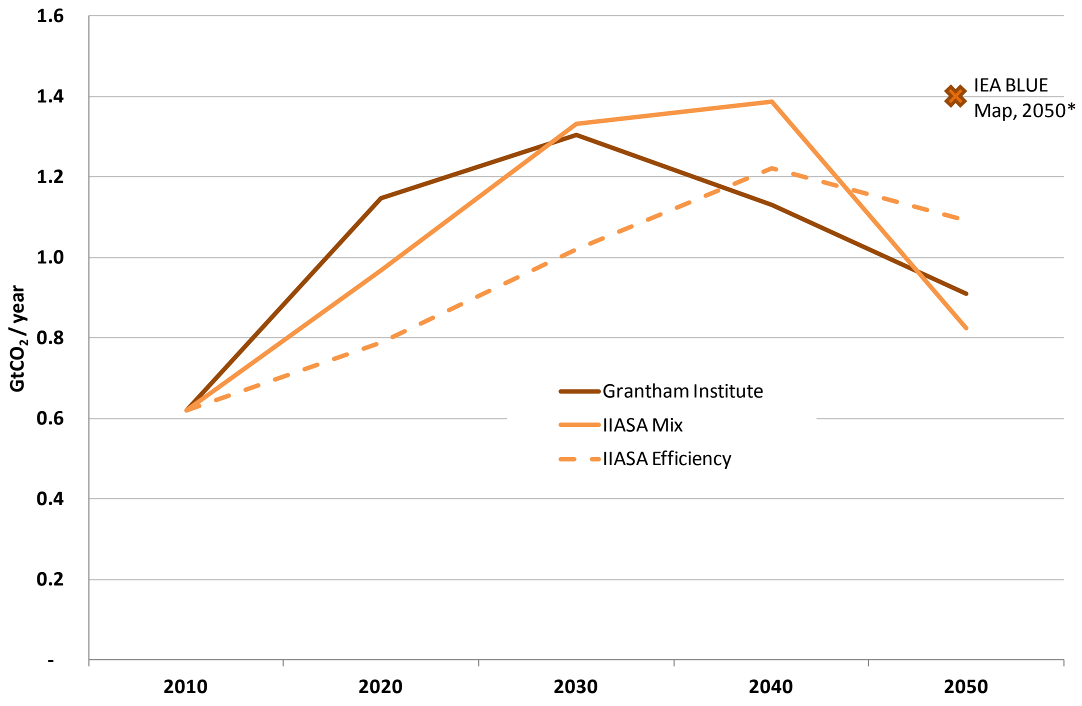

Figure 9: Transport emissions in Grantham Institute and IIASA abatement scenarios

Notes: *IEA BLUE Map scenario energy usage and emissions are on a well to wheels (not final energy) basis.

A key driver of the Grantham Institute scenario is its assumption on road transport vehicle growth. Although the scenario is based on Ou et al's (2010)[43] assumptions on penetration of electric vehicles, hybrids and biofuels, it takes a much lower 2050 vehicle population – of the order 300 million vehicles by 2050 (in line with IIASA's projections), as compared to 500 million vehicles projected by Ou et al (2010)[43]. Figure 10 shows the potential growth paths of vehicles in China compared to the historic levels in other countries, at different levels of per capita income. The Grantham Institute high growth scenario shown is based on Ou et al's (2010)[43] growth rates, and the low growth on IIASA's. A key challenge for China to achieve the levels of emissions indicated in this study will be its future urban and integrated transport and land use planning, and whether it can limit vehicle growth to, for example, Japanese levels, as is more in line with the Grantham Institute low growth scenario.

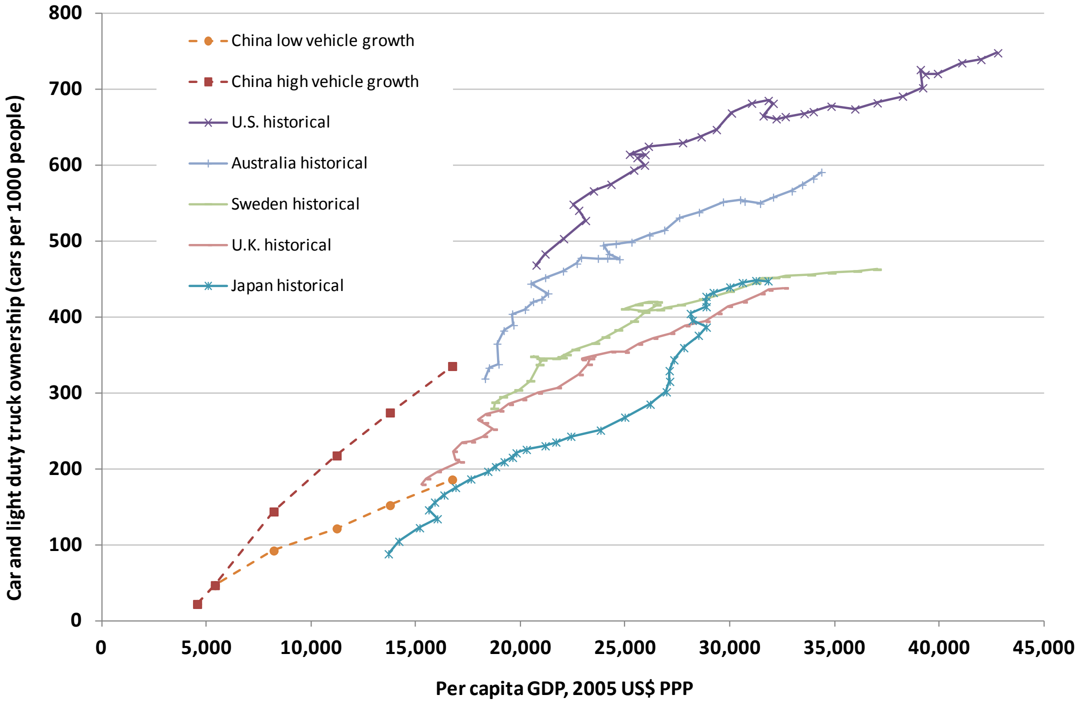

Figure 10: China's road vehicles projections and historical data for other countries[44]

There are a number of other potential low-carbon technology pathways for transport, with the IEA BLUE Map for example identifying significant hydrogen demand in 2050. Natural gas – which is already used as liquefied petroleum gas (LPG) in taxis in several cities - could also play a larger role than indicated, but this depends on the availability of gas resources in China, and alternative demands for gas in other sectors such as electricity generation and transport.

Figure 11 shows the emissions savings in the Grantham Institute abatement scenario against the Grantham Institute baseline scenario, by transport mode and major abatement measure. Road transport makes the largest overall contribution to emissions savings by transport mode, and electrification (of rail and road) combined with decarbonisation of electricity makes up the majority of overall savings.

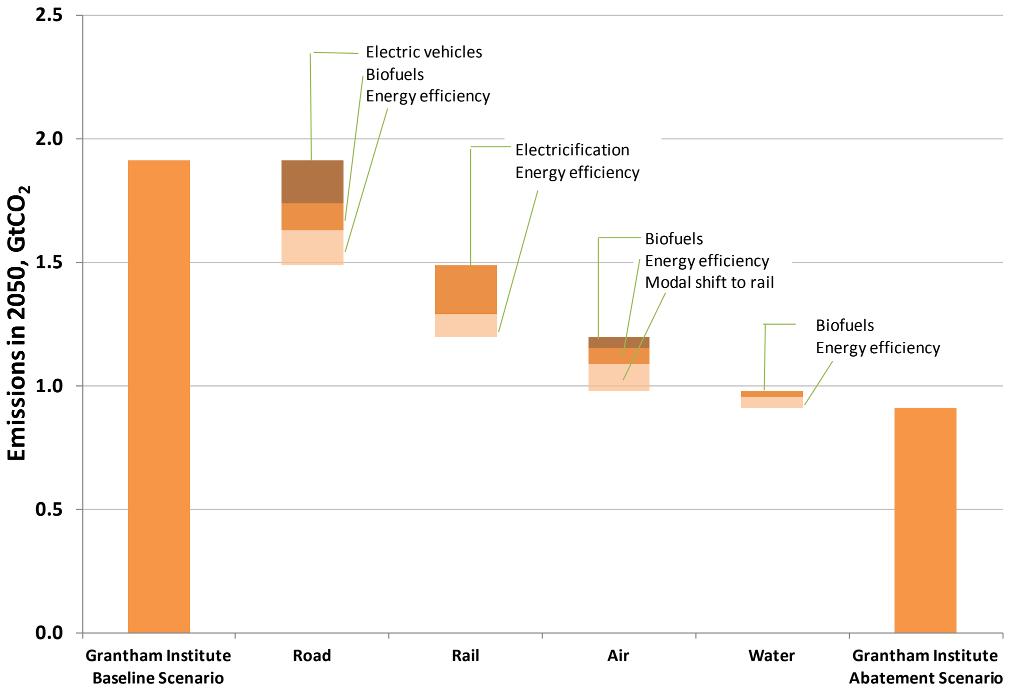

Figure 11: 2050 transport emissions savings in Grantham Institute abatement scenario, by measure

Table 4 summarises the challenges presented by scaling up these technologies. There are currently several challenges to achieving emissions savings from electric vehicles in China, including bringing down battery costs, constructing an electric charging infrastructure, and decarbonising the electricity grid. China is already seeking partnerships with a number of overseas car companies to improve its own technological capabilities in vehicle manufacture. In addition, the planning challenges for charging infrastructures that several countries now face create an opportunity for international collaboration. A number of significant abatement options, notably energy efficiency in non-road sectors, are based on relatively crude assumptions on the continuation of historic efficiency trends, and this area would benefit from further research.

Technology		2050 abate-ment potential (Gt CO_2)	Abatement cost range*	Status of technology in China/abroad	Key challenges to scale-up to 2050 levels
Road	Electric vehicles	0.17	High	• Early stage of commercialisation • Extensive experience in China of manufacturing 2-wheeler electric vehicles	• Carbon savings rely on decarbonised grid; • Lack of charging infrastructure though regional plans are emerging; • Battery energy density, cost, and production resource/energy intensity improvements required • China does not own valuable IP in many EV technology areas; • Customers aim for luxury and comfort over electric vehicle technology; • Remaining oil subsidies keep petrol prices lower.
	Biofuels	0.11	Uncertain	• Second generation biofuels are yet to be commercialised.	• Potential lack of reliable, sustainable feedstock - importance of setting and monitoring standards to ensure this.
	Efficiency	0.14	Low	• Current standard of 7.9 km/l fleet average fuel economy is the third most stringent in the world, after Japan and the EU;	• Savings depend on the degree of rebound effect (i.e. increased driving as a result of higher fuel economy); • Potential increase in larger, high-emission vehicles with improving in living standards.
Air	Modal shift to rail transport	0.11	Low	• Competition from high-speed rail impacting domestic air transport demand forecasts [45].	• For distances over 800 km, air is likely to be faster in terms of overall door-to-door journey time[46].
	Biofuels	0.04	Uncertain	• Air China Ltd., in cooperation with Boeing Co., to test commercial jet biofuel in China produced from a locally grown plant by the middle of 2011 [47].	• Competition of biofuels with road, water transport sectors; • Technology breakthroughs are required to commercialize 2nd, 3rd generation biofuels [46].
	Efficiency	0.06	Medium	• Evolutionary technology innovation could lead to fuel efficiency improvements in new aircraft of the order 35-45% by 2025 [46]	• Technologies to achieve further efficiency improvements (up to 60% by 2050) are more speculative and require R&D [46] • Air traffic management efficiency faces several challenges including safety and noise pollution [46].
Water	Biofuels	0.02	Uncertain	• There have been a limited number of projects using biofuels in ships[48].	• Competition of use of biofuels with aviation and road transport sectors.
	Efficiency	0.04	Low to medium	• China Shipbuilding Industry Corporation is optimizing shapes to reduce friction and routes to improve efficiency.	• Uncertainties as to degree of achievable efficiency savings as less research in this area
Rail	Electric	0.19	High	• Electrified share of rail transport in China in 2008 was 32.7%[49].	• Costs are high; • Carbon savings rely on decarbonised grid.
	Efficiency	0.10	Low to medium	• Several domestic companies are building trains with improved technologies including advanced engines and air brake systems.	• Uncertainties as to degree of achievable efficiency savings as less research in this area

Table 4: Summary of abatement options in the Chinese transport sector

Notes: *Low Cost = \$0-50/tCO_2; Medium Cost = \$50-100/tCO_2; High Cost = over \$100/tCO_2, using Imperial judgements based on a range of sources [30] [50]

Buildings

Emissions from the residential and commercial buildings sector (including electricity) made up about 20% of total CO_2 emissions in 2008[51]. This is a smaller share than OECD countries where buildings account for closer to 40% of total CO_2 emissions – in part this is a result of the dominance of industry in China's emissions mix, but it also reflects the smaller number of appliances per household, the widespread use of biomass in rural areas, and the lack of adequate heating facilities (for both space and water heating) in many households[52]. Uncertainties around statistics, particularly pertaining to biomass usage, could also be a contributor of this lower share of emissions. Although typical lifetimes of buildings in China are around 25-30 years[53] the rapid growth of urban population and the associated demand for residential and commercial buildings indicate that it is important that China does not lock into a high-carbon pathway in the sector over the next few decades.

IIASA's baseline scenario projects emissions from buildings will be 3.5 $GtCO_2$ in the CPA region by 2050, about 21% of total CO_2 emissions in the region. It is projected that buildings will emit 0.4 (Mix) - 1.1 (Efficiency) $GtCO_2$ in 2050 in the IIASA abatement scenarios, 19% of total CO_2 emissions in the Mix scenario and 23% in the Efficiency scenario by 2050.

IIASA's energy demand modelling for buildings assumes a high penetration of very energy-efficient "Passivhaus" standard housing, and a large-scale shift from biomass and other low-quality fuels towards electricity and natural gas, but does not explicitly state the mix of technologies that will in combination lead to the level and mix of final energy demands. The Grantham Institute has therefore developed a bottom-up model of the buildings sector in China to assess in greater detail the technology mix in an abatement scenario. The key assumptions are as follows:

- **Buildings growth:** Growth in the sector is driven by household habitation (persons per household) as a function of GDP per capita in urban and rural residences, and commercial floor space as a function of service sector value added;
- **Heating and cooling demands:** The model subdivides China into three regions – a cold, Northern region where district heating is the dominant heat supply technology; a Transition region with cooling and higher penetration of electric resistive heating ('Yangtze' region); and a Southern cooling/dehumidification region;
- **Electricity:** the carbon intensity is assumed to be that of the IIASA Mix abatement scenario.

As shown in Figure 12, Grantham Institute's scenario has lower emissions than both the IIASA scenarios throughout the period to 2050, with emissions levels very similar to the IIASA Mix scenario from 2030. The Grantham Institute analysis therefore suggests that more aggressive emissions savings are possible in the early decades, but this is based on continued use of biomass throughout the period to 2050, albeit with vastly increased efficiencies due to high efficiency conversion technologies and a shift towards commercial sources. This is also reliant on the assumption that biomass emissions would be zero (i.e. that biomass heating and cooking is from genuinely renewable sources). The IEA's BLUE Map emissions for 2050 are higher than in the Grantham Institute scenario, as the assumed electricity CO_2 intensity is higher (121 gCO_2/kWh) than the Grantham Institute level of below 50 gCO_2/kWh (based on IIASA's Mix scenario) by 2050.

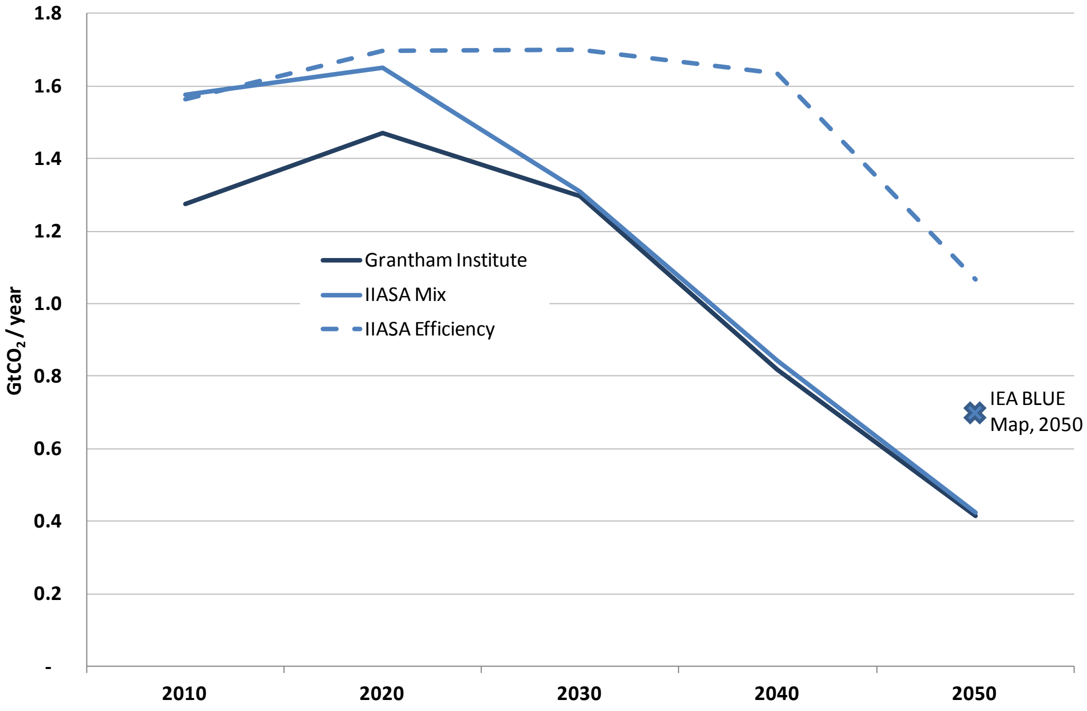

Figure 12: Buildings emissions in Grantham Institute and IIASA abatement scenarios

Figure 13 shows the major emissions saving options and measures in the Grantham Institute abatement scenario. The key mitigation options in the Grantham Institute abatement scenario are efficiency of lighting, appliance and cooling equipment, and the decarbonisation of electricity used by this equipment. Additional key abatement options include low carbon electricity for heating (essentially heat pumps, which achieve a particularly high penetration in the transition areas); and an expansion and increased operational efficiency of district heating schemes in Northern areas, supplied by advanced heating technologies (e.g. Fuel Cell CHP).

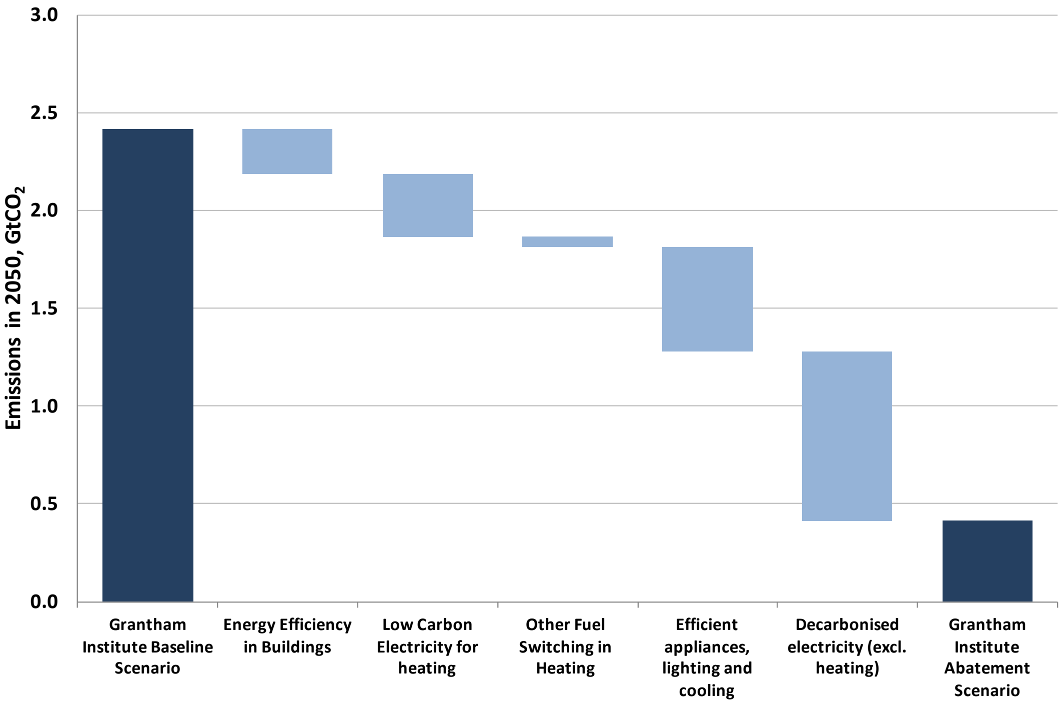

Figure 13: 2050 emissions savings in Grantham Institute abatement scenario, by sector and measure

A number of different studies assume varying levels of efficiency improvements in the baseline, with for example the IEA and IIASA's own baseline assuming a more "frozen" level of technology, and little efficiency improvement. By contrast, the Grantham Institute's own modelling - in common with that of Lawrence Berkley National Laboratory(2011)[20] - assumes that, as the Chinese building stock grows, newer, more efficient technologies with higher levels of efficiency are implemented. This is arguably a more realistic assumption given historical developments.

The key challenges to scaling up the abatement measures are outlined in Table 5. In the Grantham Institute abatement scenario, building envelope efficiency reaches, on average, a level which is consistent with the Carbon Trust/AECB Silver Standard (40 kWh/m^2 for heating). This is more ambitious than the levels of energy efficient building envelope assumed in the IEA BLUE Map scenario, but less so than IIASA's high penetration of Passivhaus-standard housing (15-30 kWh/m^2). This would require not only close agreement and coordination between regional and central governments, but a highly accelerated ramp-up of institutional capabilities to draft, enforce and monitor ambitious building codes before 2020.

A high seasonal Coefficient of Performance (CoP) of 4 has been assumed for heat pumps in 2050, which is comparable to current Japanese best practice. However poor heat pump installation and operation can lead to lower CoP values and it is assumed that peak demand is met by resistive (and thus lower CoP) heating in an optimised package. As a result, the savings from the large-scale roll-out of heat pumps envisaged here would require a co-incident push for conservation measures and training, monitoring and awareness programmes. For CHP, systems using low-carbon fuels, such as fuel cells, will require significant development to attain commercially viable cost levels. In addition, the successful development of low-carbon district heating will require a degree of planning and foresight that will prove challenging in fast-urbanising regions within China.

A continued increase in appliance efficiency is assumed which would require the Chinese appliance stock to reach efficiency levels comparable to Japanese best practice standards of ten years ago, a near-doubling of efficiency across the main appliance categories. This would require ambitious new regulation and strict labelling, testing and monitoring of appliances.

Overall the challenges to decarbonising the buildings sector are characterised not by the development of new technologies (most of which already exist, and which are in use in different regions of the world), but by the requirement to ensure that strict standards for efficiency and the use of low-carbon technologies are enforced. As a number of other countries face a similar challenge of implementing (in many cases low cost or even negative cost) energy efficiency and low-carbon buildings measures, there are likely to be numerous opportunities for collaboration with China in this area.

The Grantham Institute modelling currently assumes a largely uncoordinated urban land use development, and does not differentiate rates of urbanisation in different regions. It therefore does not reflect the energy and CO_2 savings potential across different sectors arising from integrated urban planning. In addition, projecting energy demand for commercial buildings is problematic: the efficiency of commercial services per square metre is constantly increasing, and there are significant uncertainties around the level of future demand per square metre. Over the last decade there has been significant urban sprawl in a number of China’s cities, although in 2010 a number of recent low carbon pilot provinces and cities were announced, as discussed in a later section (“Cross cutting issues”) of this study. The future development pattern of China’s cities as it continues to urbanize will be a major factor driving emissions from buildings and transport.

Technology	2050 abatement potential ($GtCO_2$)	Abatement cost range*	Status of technology in China/ abroad	Key challenges to scale-up to 2050 levels
Low carbon heating (CHP, heat pumps and solar thermal)	0.53	Negative to Low	• Mature in China and elsewhere; High penetrations in Northern and Central Europe; • Support for large-scale heating installations, small-scale CHP non-existent; • Depending on technology and application, pre-commercial /early-stage commercial.	• District Heating schemes are operated inefficiently (billing practices not based on actual consumption); • Innovation and institutional capacity with regard to financing is necessary; • General lack of exposure to energy and CO_2-saving technologies among developers and government; • Lack of accredited installers; • Degree to which traditional biomass will be phased out and the marginal technology that will substitute it present key uncertainties; • Generous subsidies for coal – lower costs for incumbent technology.
Lighting, cooling and appliances	1.24 (of which 0.87 from electricity decarbonisation)	Negative to low	• LEDs for residential lighting are early stage, CFLs are commercial and widespread in China; • Other technologies largely commercial.	• Institutional capability requires accelerated ramping up; monitoring, implementation, and ambitious regulation will be necessary to ensure the savings potential is achieved; • Highly fragmented markets for many appliances increase difficulty of regulation and monitoring[54]; • Strong industry lobbying has stalled the growth of the green appliance market (e.g. delayed, weak AC standards).
Energy efficiency in buildings	0.23	Negative to low	• Established standards in Northern and Central Europe; but currently low penetration of low-carbon housing in China.	• Different climate zones require regional policies and targets, which present barriers for monitoring and implementation; • Challenging to achieve effective implementation of standards given potentially competing regional economic development objectives; • Growth in building stock too high, standards unable to keep up; • Principal-agent issues, particularly in the commercial sector [55].

Table 5: Summary of abatement options in the Chinese buildings sector

Notes: *Low Cost = $0-50/t$CO_2$; Medium Cost = $50-100/t$CO_2$; High Cost = over $100/t$CO_2$, using Imperial judgements based on a range of sources[3 30 40 42]

Total emissions savings

Combining the analysis for the industry, transport and buildings sectors allows a comparison of the projected savings in the Grantham Institute and IIASA scenarios. Figure 14 shows the energy demand (by fuel type) in 2050 in the Grantham Institute baseline and Abatement scenarios, as compared to the IIASA baseline and Mix scenarios.

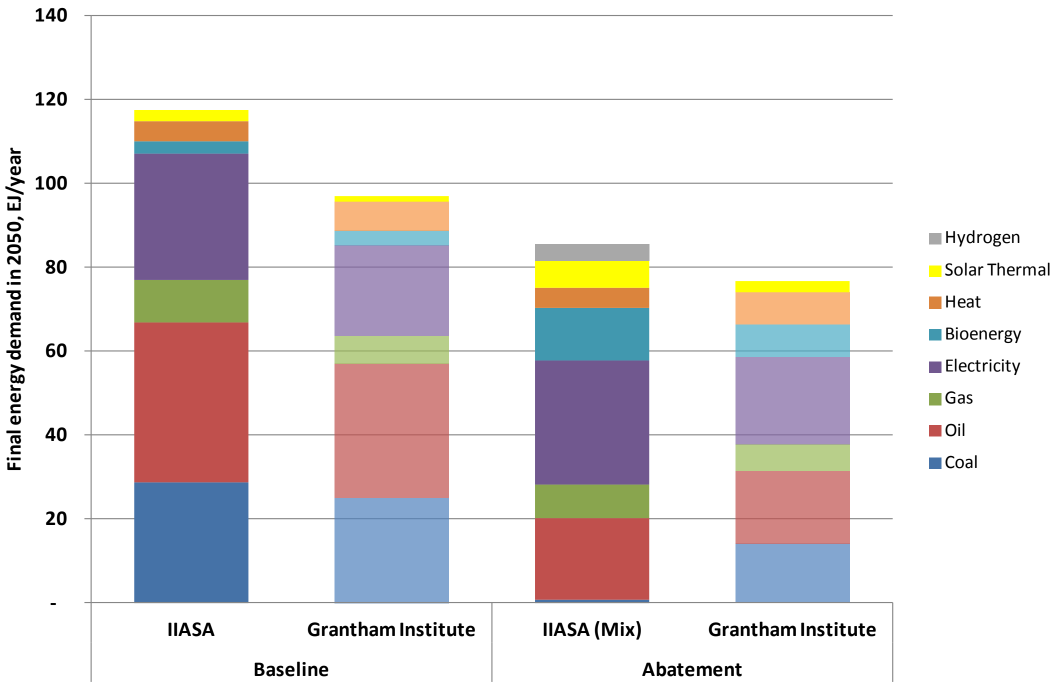

Figure 14: Final energy demand in Grantham Institute and IIASA scenarios

In general the energy demand projected by the Grantham Institute scenarios is lower than that in the IIASA scenarios, for the both the baseline (17% lower) and abatement (11% lower) scenarios. For the baseline this partly reflects the greater energy efficiency improvements assumed in the Grantham Institute's business-as-usual projections, whilst for both the baseline and the abatement scenarios the Grantham Institute projections are lower as they are for China alone rather than the (approximately 10% larger in GDP and population terms) CPA region.

It is worth noting that the composition of energy demand is rather different in the two abatement scenarios shown in Figure 14 - there is far more coal in the Grantham Institute abatement scenario relative to the IIASA Mix scenario, and about 10 EJ/year less electricity demand. Coal demand is higher principally because IIASA assumes a range of substitutes (including biomass) for coal used as a feedstock in the industry sector, whereas the Grantham Institute's modelling is more conservative and assumes that, by 2050 at least, there will be relatively limited opportunities to replace coal as a feedstock in non-metallic minerals and iron and steel production. The greatest difference in electricity demand is in the buildings sector, where IIASA's modelling shows a much greater use of electricity in lighting, appliance and cooling compared to the Grantham Institute's modelling. This could be the result of less aggressive assumptions by IIASA on the energy efficiency improvements of this electrical equipment, where the Grantham Institute's research indicates significant potential.

As shown in Figure 15, the higher coal demand in the industry sector in the Grantham Institute abatement scenario contributes to higher overall emissions compared to the IIASA Mix scenario. However, overall savings are lower across all sectors: in transport the IIASA Mix scenario has a slightly lower oil demand than the Grantham Institute abatement scenario, but the total savings are principally lower due to the fact that the emissions in the Grantham Institute baseline scenario are lower than in the IIASA baseline scenario. In the buildings this is also true. In addition, in the buildings sector the savings resulting from the greater electrification in the IIASA Mix abatement scenario and lower reliance on coal and oil relative to the Grantham Institute abatement scenario mean that the Grantham Institute abatement scenario shows smaller emission savings compared to the IIASA Mix scenario. Nevertheless, the IIASA and Grantham Institute scenarios report a broadly similar message – that emissions from these end-use sectors (which includes electricity emissions) could be reduced to below 3 $GtCO_2$ in China by 2050.

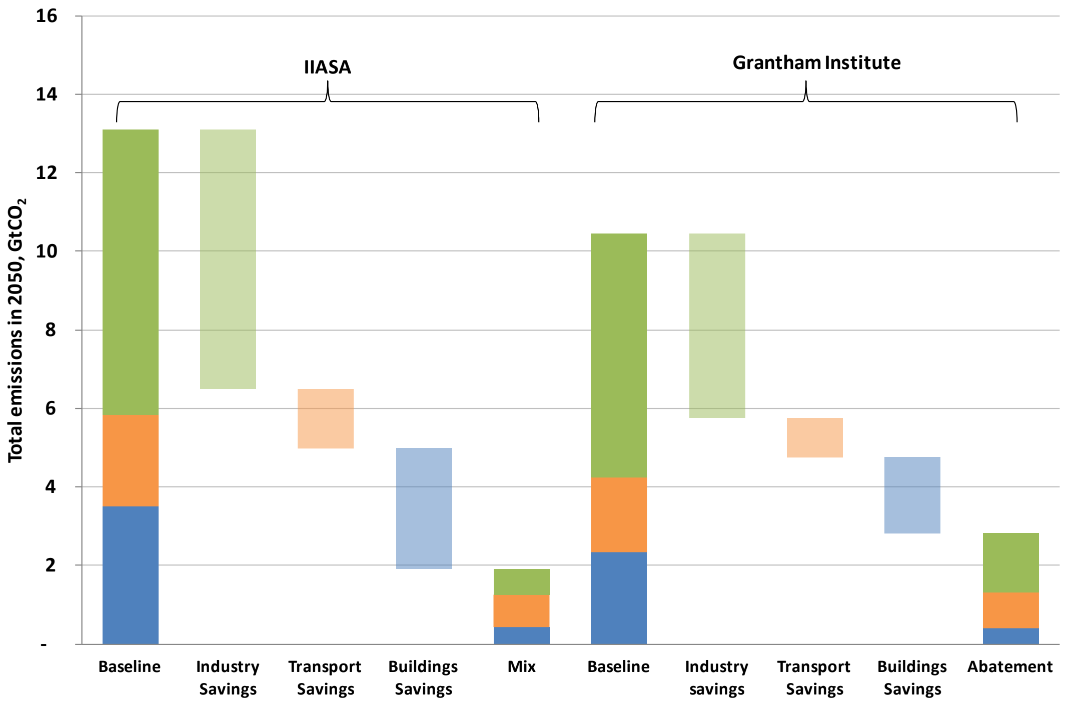

Figure 15: Emissions savings in Grantham Institute and IIASA scenarios in 2050

Notes: Emissions from energy conversion not included - these are 2.8 $GtCO_2$ in the IIASA baseline and 0.4 $GtCO_2$ in the IIASA Mix scenario by 2050.

Comparison of low carbon scenario with other studies

Table 6 compares the 2050 CO_2 emissions remaining in each sector in the Grantham Institute abatement scenario with those in the IEA (2010) and LBNL (2011) low carbon scenarios, for which comparable data is readily available. These show that, in spite of the differences in 2050 emissions, a similar share of emissions is expected to remain in Industry (about a half of total emissions), transport (about a third of total emissions) and buildings (about a sixth of total emissions). This compares with 2008 figures where Industry made up over two-thirds of emissions, buildings a fifth and transport less than a tenth.

Scenario	**2050 energy CO_2 emissions, Gt**	**Emissions share by sector**		
		Industry	**Transport**	**Buildings**
Grantham Institute Abatement	2.8	53%	32%	15%
IEA BLUE Map	4.3	49%	34%	17%
LBNL Accelerated Improvement	7.4	58%	28%	14%

Table 6: Energy-related CO_2 emissions and share by sector in selected studies

Notes: LBNL scenario is not part of an explicit global $2^{O}C$ trajectory, unlike Grantham Institute and IEA.
Data for IEA/LBNL derived from published charts rather than underlying data.

Sensitivity analysis

There are a wide range of uncertainties when projecting to 2050. For example, in the industry sector, it is unclear the degree to which China will have transitioned away from heavy (energy-intensive) industry. In addition, the deployment of carbon capture and storage is responsible for a significant share of emissions reductions by 2050, yet this technology has not yet been commercially proven in industrial applications, so there remains a possibility that it may not be viable. Finally, the Grantham Institute abatement scenario uses IIASA's Mix scenario's electricity CO_2 intensity value, where electricity becomes highly decarbonised (below 50 gCO_2/kWh) by 2050. Figure 16 illustrates how industrial emissions (including indirect emissions from electricity) would change if these assumptions were changed. With heavy industrial production increased by 25%, overall industry emissions would increase by about 0.1 $GtCO_2$ by 2050. Without CCS, industrial emissions would increase by about 0.6 $GtCO_2$ by 2050. Using the IIASA Efficiency scenario's electricity CO_2 intensity (280 g/kWh by 2050), overall industry emissions would increase by about 0.9 $GtCO_2$ by 2050.

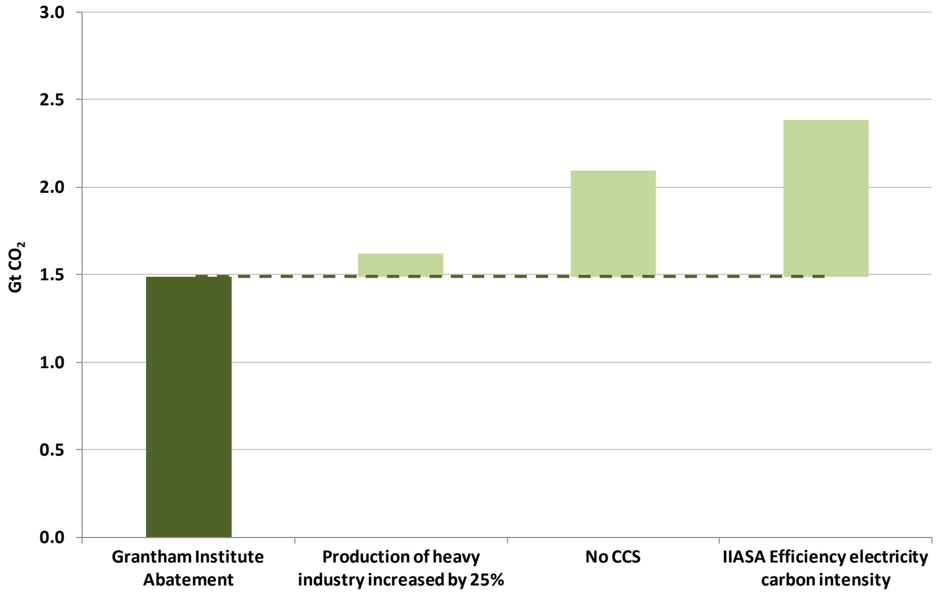

Figure 16: 2050 industry CO_2 emissions with sentitivities

In the transport sector, key uncertainties in the modelling include the degree to which biofuels replace oil products in the air and water transport sectors, electricity CO_2 intensity, and the road vehicle stock by 2050. Figure 17 illustrates how variations in these assumptions would change overall transport emissions by 2050. The most significant increase in emissions (an additional 0.3 $GtCO_2$ by 2050) would result from an assumption that China has about 500 million road vehicles (excluding motorcycles) by 2050 (in line with the assumption by Ou et al (2010)[43]), rather than just over 300 million, as assumed in the Grantham Institute model.

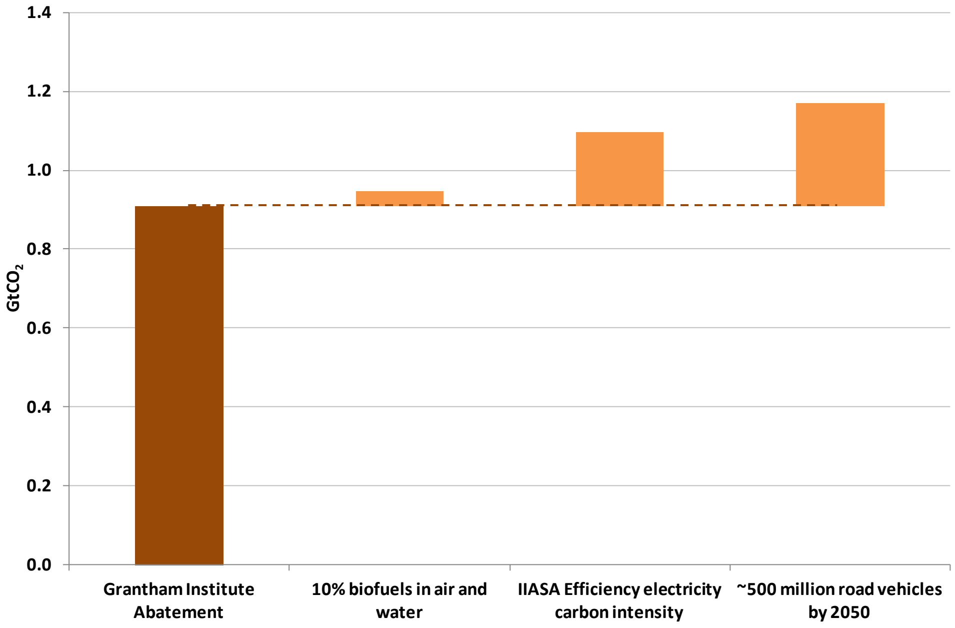

Figure 17: 2050 transport CO_2 emissions with sensitivities

For buildings, figure 18 illustrates that a 25% higher assumed level of residential and commercial floor space by 2050, with associated increases in energy service demand, would see emissions increase broadly in line with floor space. Using IIASA's Efficiency scenario's electricity CO_2 intensity almost doubles overall buildings emissions, as there is significant electrification of all buildings energy services by 2050.

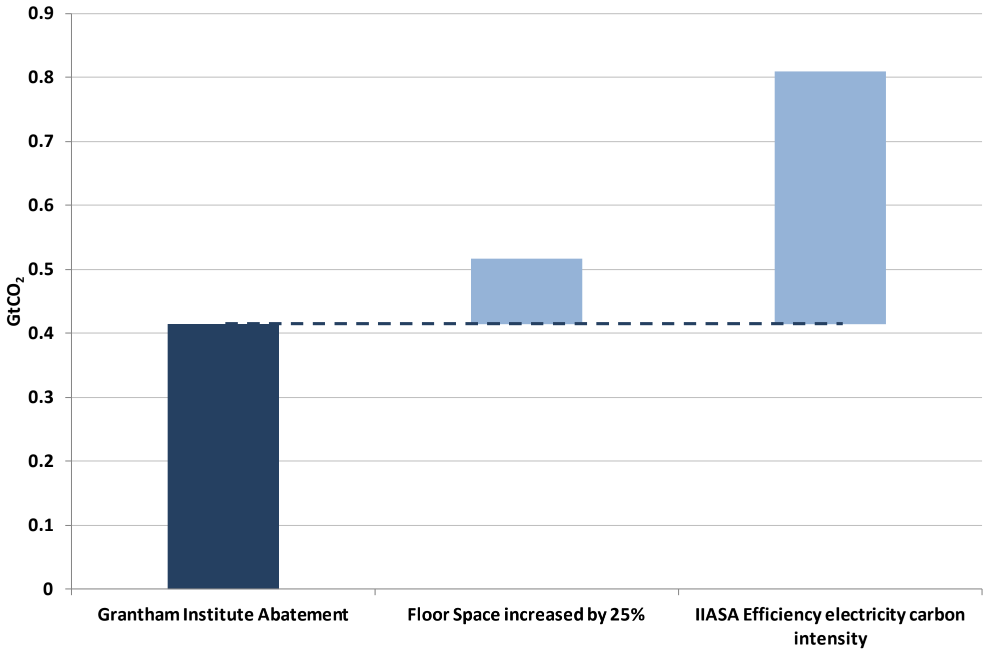

Figure 18: 2050 buildings CO_2 emissions with sensitivities

The overall impact of the higher electricity CO_2 assumption is to add about 1.5 $GtCO_2$ to 2050 emissions, about a 50% increase on the Grantham Institute abatement scenario, underlining the importance of achieving a highly decarbonised electricity generation system by 2050.

Cross cutting issues

China's low carbon development pathway would see the deployment of a range of new technologies, which in combination will have different resource use implications to more carbon intensive technologies. In this section the specific implications for land and water usage, fossil fuel and uranium resource usage, and spatial network planning are considered.

Land usage

The IIASA abatement scenarios do not envisage any significant net increase in bio-energy by 2050, but traditional biomass (used largely for residential heating and cooking) is phased out and replaced with an increase in biofuels for transport and biomass energy for industry.

Total biomass for primary energy use remains in the region of 8 EJ/year. Figure 20 shows, however, that there is considerable potential for further increasing the contribution of biomass, provided that a greater share of China's extensive grasslands could be brought into play. Using grasslands for biomass production is closely linked to the development of second generation "cellulosic" biofuel technology, making it possible to use a wider variety of biomass sources, including fast-growing grasses or trees, crop or forest residues, and even paper waste. However, many factors must be taken into account when assessing the suitability of using grasslands in this way, including alternative uses of this land, the effect on local populations and biodiversity, as well as the direct and indirect emissions from the harvesting of such biomass. In addition, the transport of such energy sources, as well as other constraints such as nutrient and water management (which could to a large extent depend on the effects of climate change), are likely to be challenges in this area.

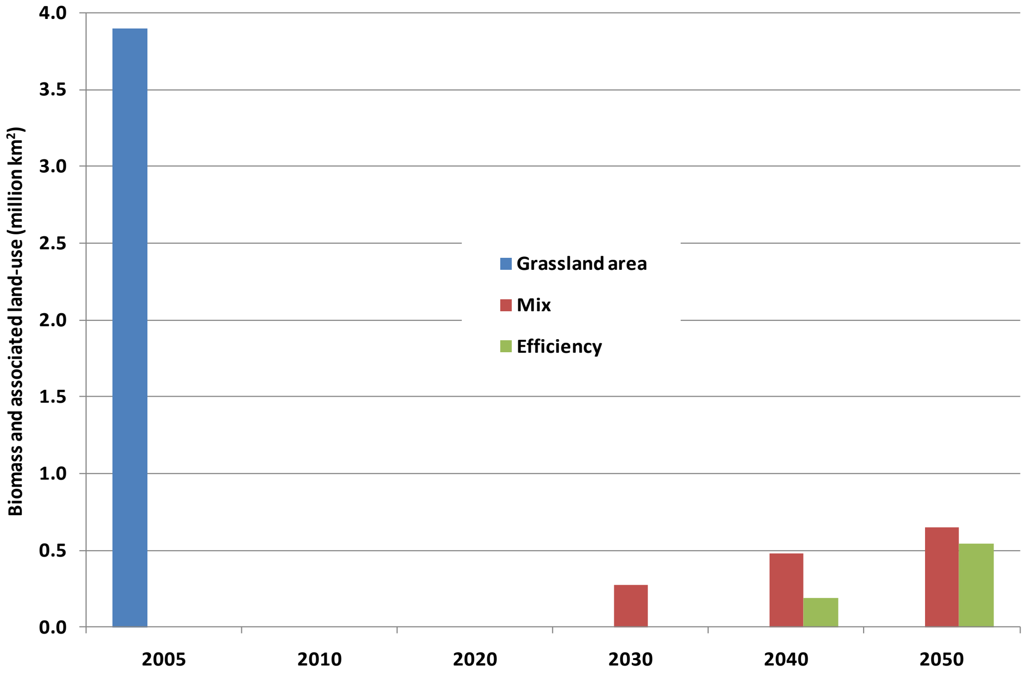

Figure 20: Land-use implications of purpose grown biomass in the CPA region[22] [56]

Water usage

China faces the prospect of increasing pressure on water resources, with a severe shortfall in some of the most highly industrialised parts of the country and a moderate gap in many other regions. Overall water demand in agriculture is projected to be over 400 billion m^3 by 2030 (assuming a static policy regime and existing levels of efficiency and productivity), but industry and power generation could demand over 250 billion m^3 by 2030[57]. There may be a range of impacts on water supply in western China as a result of climate change, as a result of earlier spring snowmelt and declining glaciers[58]. The 'North to South Water Transfer' is one example of an immense infrastructure project seeking to transfer water from the southern Yangtze river to the industrial north[59].

Purpose grown biomass could have considerable additional water requirements. Figure 21 shows various estimates of the biomass water requirements of the IIASA Efficiency and Mix scenarios, based on international experience with different crops. While the ranges between different examples are very large, the scale of demand suggests that water will be an important factor in China's choice of biomass options.

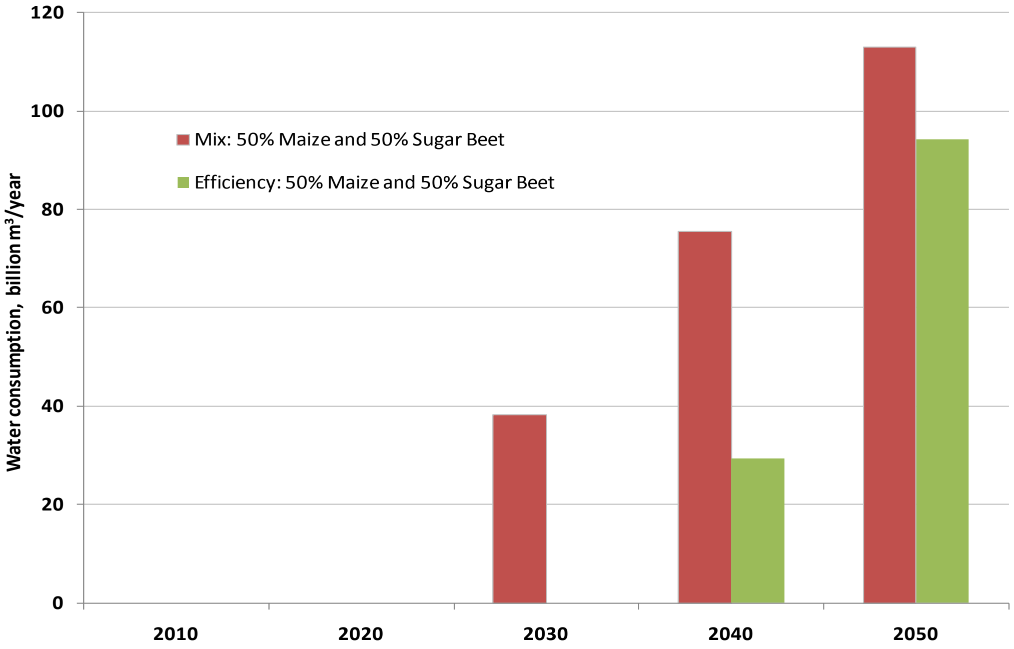

Figure 21: Water consumption of biomass in the CPA region in IIASA scenarios[62]

Notes: There is a wide range of values for water usage reported in the literature, with some attributing no increase in pressure on water resources to increased biomass production (e.g. the European Commission 2005 Biomass Action Plan[60]) whilst others account for the water footprint, defined as: "The volume of fresh water used for the production of that product at the place where it was actually produced"[61].

Figure 22 shows the volumes of water consumed annually in power generation in the IIASA abatement scenarios. The Figure shows hydro, where water evaporation is an issue, as much the largest consumer of water, with most of the remainder consumed in coal power stations, and then in nuclear stations as the nuclear programme grows. Whilst in aggregate the additional water consumption is small compared to water that could be used in bio-energy production, local water availability will be an important consideration for the location of particular generation plants.

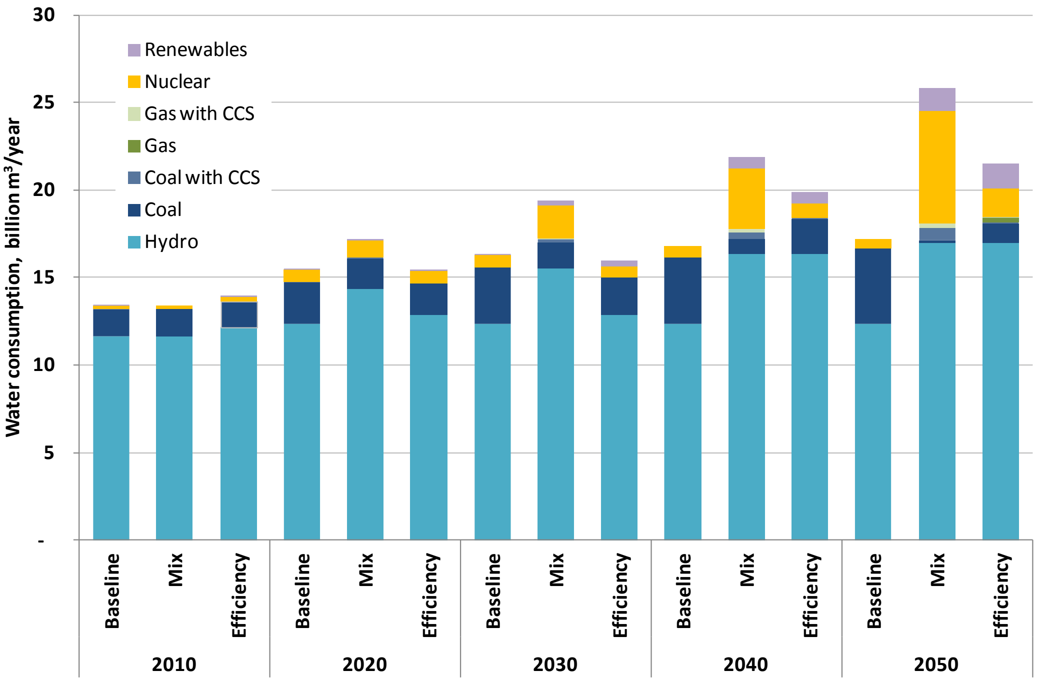

Figure 22: Water consumption in the power sector in CPA, by generation technology[62]

Notes: Assumed power generation types for water consumption calculations; Sub and super critical coal once through cooling cycle, IGCC wet tower, IGCC with CCS wet tower, nuclear wet tower PWR, Oil once-through, gas once-through, gas with CCS wet tower, solar thermal wet cooling.

In addition to the water resource impact of biomass production and electricity generation, the impact of water demand from coal-to-liquids technologies and non-electricity uses of CCS for instance may also prove significant, although these have not been assessed quantitatively here.

Oil demand

China's oil reserves stand at an estimated 14.8 billion barrels, about half those of the US and 6% of Saudi Arabia, and equivalent to 11 years of current production[63]. In view of the assumed continuing growth of the economy as a whole, all of the IIASA scenarios imply increasing oil demand to 2030, but with decreasing demand in the abatement scenarios thereafter, as shown in Table 7. To set these figures in context, China's domestic oil production is expected to stabilise at its 2009 level of about 4 million b/d[64], and is unlikely to increase beyond that in the future. Hence demand will outstrip domestic production throughout the period to 2050 in all three scenarios, indicating that China will continue to be reliant on imports. In any case total cumulative demand (at around 150 billion barrels) in the abatement scenarios is some ten times China's current oil reserve estimates. A similar result is found in the SPRU/Tyndall (2009) abatement scenarios[19]. However, it is likely that the official reserves are considerably underestimated, with some studies (e.g. LBNL (2011)) using estimates of the order 100 billion barrels of ultimate recoverable reserves[20].

IIASA scenario	Primary oil demand, million barrels per day (b/d)				
	2010	**2020**	**2030**	**2040**	**2050**
Baseline	8.3	12.0	13.7	17.0	16.1
Mix	8.3	12.2	13.3	13.1	7.3
Efficiency	8.3	9.7	11.1	12.3	9.4

Table 7: Projected oil demand in the CPA region for IIASA scenarios

China National Petroleum Corporation (CNPC) plans to spend $60 billion to expand overseas production to 4 million b/d by 2020[7]. This expansion seems likely to continue as China's National Oil Companies seek to acquire new reserves to replace their used-up oil wells[65]. On IIASA's projections for China's domestic production this could approximately meet China's oil import needs, although on the IEA's less optimistic forecasts only about half of China's imports would be replaced by this CNPC production[6].

In principle, coal-to-liquids (CtL) technology, which has been demonstrated in China, represents another option for meeting oil demand, depending on its cost relative to oil prices. However this may be restricted by water supplies, with 1 tonne of coal-to-liquids fuel requiring 10 tonnes of water input[8]. In addition, CtL processes at scale could lead to significant CO_2 emissions unless mitigation measures such as CCS are simultaneously deployed, as has been assumed in IIASA's low-carbon scenarios. For China, therefore, growing oil import dependency represents a serious strategic and economic concern, and a strong reason, in addition to environmental considerations, for adopting oil conserving measures such as those in IIASA's abatement scenarios, which by 2050 would approximately halve primary oil demand relative to the baseline.

Gas demand

China's conventional natural gas reserves stand at 2.46 trillion cubic metres (about a third of US reserves, 6% of Russia, and 1.3% of global reserves), representing 29 years of current production[63]. However, recoverable reserves of unconventional gas, such as coal bed methane and shale gas may be more than three times conventional reserves[7]. In fact a recent US Energy Information Administration study suggests that China's technically recoverable shale gas could be about 36 trillion cubic metres, over ten times conventional natural gas reserves[66].

In the IIASA Mix scenario, the share of gas in primary energy demand increases from 4% in 2010 to 22% in 2050, by which time gas has become China's second largest source of primary energy, only exceeded by coal. Most of this gas is expected by IIASA to come from domestic sources, with 14% supplied by imports in 2050. In contrast, the IEA expects that

China will be importing more than half its gas supply by 2035[6]. With regard to other studies, SPRU/Tyndall (2009) estimates that total gas demand over the period 2005-2050 in all its abatement scenarios would far exceed (by a factor of 5 to 10) conventional Chinese gas reserves[19], whilst LBNL (2011) estimates that China would be importing at least 75% of its gas needs by 2050[20], underlining the importance of achieving both secure access to gas from overseas, and unconventional sources from within China.

IIASA scenario	Primary gas demand, billion cubic metres / year				
	2010	2020	2030	2040	2050
Baseline	97.9	98.5	133	252	385
Mix	97.9	117	213	507	747
Efficiency	97.5	99.0	133	236	456

Table 6: Projected gas demand in the CPA region for IIASA scenarios

In the IIASA Mix scenario, there is a progressive increase in the share of domestic production coming from unconventional sources, which contribute more than half of total production by 2040. The CNPC has entered into joint ventures with a number of international companies to develop unconventional gas resources and China signed an agreement with the US in November 2009 to co-operate on shale-gas development. China is also engaged in major efforts to expand its gas infrastructure, in terms of pipelines and LNG import terminals to access international supplies.

The extent of the contribution of gas to China's future energy mix is very uncertain. It depends on China's success in following the example of the US in developing unconventional gas reserves, on international negotiations for pipeline supply mainly from Russia and Turkmenistan, and on the international LNG market in which China will compete for supply notably with Japan. Recent research has, however, highlighted the methane gas released in shale gas developments in the US and questioned the climate change benefits of shale gas as compared to coal[67].

Coal demand

Coal is currently the lowest cost and most accessible form of energy in China, and makes up 71% of China's primary energy supply and four-fifths of electricity generation[7]. China is also, by far, the largest coal producer in the world, with output of more than 2 billion tonnes in 2008, more than double US production[6].

In the IIASA baseline scenario, coal continues to dominate primary energy demand, with demand approximately doubling between 2010 and 2050. This is compared with a peaking of coal demand between 2020 and 2030, as shown in Table 7, in both the IIASA abatement scenarios. The feasibility of increasing production on the scale implied by the baseline scenario can be questioned not only on environmental and health grounds but also in relation to accessible coal reserves, and their transportation to demand centres.

While China's total coal reserves are vast, at 4552 Gt of proved exploitable reserves, the only coal resources taken into account for detailed planning purposes are about 115 Gt, representing about 50 years at current production rates, and enough to satisfy 2010-2050 demand in the IIASA abatement scenarios but not the IIASA baseline scenario (for comparison, the SPRU/Tyndall (2009) abatement scenarios[19] and the LBNL (2011) more aggressive accelerated improvement scenario[20] also use less coal than available reserves/production to 2050). Further exploration can be expected to increase these proven reserves, but future reserves will not be as accessible as those mined in the past[68].

IIASA scenario	**Primary coal demand, Gt / year**				
	2010	**2020**	**2030**	**2040**	**2050**
Baseline	2.90	3.81	4.48	5.32	6.58
Mix	2.90	2.79	2.21	1.73	1.64
Efficiency	2.82	2.56	2.46	2.13	1.47

Table 7: Projected coal demand in CPA region for the IIASA scenarios

Coal mining has so far been concentrated in the Provinces nearest to the centres of demand in Eastern China. However, by far the largest remaining forecast reserves are further to the West, for instance in Xinjiang province[68], some 3,000 Kilometres west of the East coast. The majority of the reserves at less than 1000 metres depth, and therefore relatively economic to mine, are also in Xinjiang Province, but a lack of transport infrastructure, scarce water resources and fragility of the ecosystem are potentially major barriers to accessing this[64].

Some 50-60% of China's coal production is from big state owned mines equipped with state of the art technology (the US mining company Peabody is a major supplier of advanced longwall equipment). However 30-40% of production is from town, village, and enterprise mines with low average rates of extraction, much less advanced equipment, and in some cases poor safety records[8]. The Chinese authorities have attempted, in the past, to close the less efficient mines but have been frustrated by the pressure of rapidly increasing coal demand.

In 2009 China imported some 100 Mt of coal and in 2010 this rose to 170 Mt[8]. This was less than 10% of China's demand but large enough, in relation to internationally traded coal, to have a big impact on world markets. As well as supplies from Australia and Indonesia, China is establishing deals with Russia and is becoming increasingly involved with Mongolia which has massive coal deposits but as yet minimal infrastructure.

The rate of growth of China's coal power generation is likely to be constrained by policy considerations but also by the difficulties of modernising the less advanced part of the mining industry and the limitations of the reserves that are currently accessible to centres of demand. China will face a strategic energy policy decision of how much investment to make in infrastructure to bring coal from the far West. This could take the form of railways to transport coal or high voltage direct current lines (HVDC) to bring power. Other options include synthetic natural gas (SNG) and coal-to-liquid technology. China’s strategy of developing giant coal-power bases, integrating mining and generation, suggests that China may adopt a coal-by-wire approach, which may provide added flexibility for opening up new regions for renewable generation. Whether new transmission is cheaper than new railways over these distances is a debatable question [8]. A recent study suggests that the optimal strategy might be for heavy investment in HVDC lines to Shaanxi Province in central China, but rail links to bring coal from Xinjiang in the far West. This is on the grounds that power generation in Xinjiang may be constrained by lack of water [69]. But transport of coal over rail would have CO_2 emissions implications unless – as has been assumed in the Grantham Institute analysis - freight rail becomes fully electrified by 2050.

A final consideration for coal demand is its potential usage in Coal-to-liquids processes, which, as discussed above, could certainly reduce China’s oil demand, but at the expense of increased coal and water demand and increased CO_2 emissions.

Nuclear fuel

A rough estimate using an average consumption (in a ‘once-through’ cycle) of 200 tonnes of uranium (tU) per GWyr shows that a linear increase in uranium-fuelled power generation capacity to 300 GW by 2050 (around the level projected in IIASA’s Mix abatement scenario) would require around 1 MtU by 2050. The current estimated reserves in China are 0.1 MtU[70], with global reserves of conventional uranium estimated at 5.4 MtU[3,71]. Both of these estimates may be conservative, since global nuclear generation levels have not to this point been high enough to drive the search for new sources for some time. Nevertheless it is likely that uranium supply will be a key strategic issue for China. Alternatively, China may choose to develop capabilities in thorium fuel cycles (as in India), in advanced fuel reprocessing or, in the longer term, in fast breeder reactors. Each of these technologies would reduce the reliance on uranium whilst increasing fuel economy, but would require significant long-term investment with uncertainty around the eventual competitiveness of the technology.

Electricity transmission and distribution

The development of China’s power grid represents a critical opportunity to provide the underpinning for a low carbon energy economy of the future. Because the basic frameworks of power infrastructure tend to be long lasting, the grid investments that China makes in the coming decade will influence the structure of its energy economy in 2050. The existing high voltage grid is currently concentrated in Eastern China with a limited linkage to Western and Southern China. China's wind power potential is concentrated along the East coast and also in Northern China. Although China is the world leader in wind power by installed capacity, more than half the electricity generation has gone unused because of the limitations of the grid connections[72]. China's greatest solar power potential is in the far West, and the hydropower potential is concentrated in the South West region, which is estimated to have about 500 GW of potential[73].

Developing the grid is central to low carbon options for China's energy supply, not only because of the need to access renewable energy from across the country, but also because low carbon solutions, especially for transport and buildings and industry, are expected to require a much greater penetration of electric power in these sectors. The larger contribution of variable renewables to the power generation mix in the abatement scenarios, as well as the increase in new forms of electricity demand such as electric vehicle charging and heat pumps, will also require an increasingly flexible or smart grid.

The Chinese government has a major programme of investment in upgrading the grid, including the integration of regional networks. For the first time, in 2008, investment in the transmission grid was greater than that in the generation sector. In 2009, the State Grid Company invested $44 billion into grid infrastructure and intended to increase this by $33 billion, in 2010[7]. The 12th Five Year Plan includes an ambitious programme of enhancing West-East transmission and the establishment of five strategic energy bases including the Far west (Xinjiang) the North (Inner Mongolia), and Southeast China[74]. While this is mainly focused on the more efficient use of coal it also opens the door to better use of renewables.

Urban planning

The urban population in China is expected to exceed 1 billion by 2030 from around 600 million today, which would have a great impact on transport infrastructure and urban form[75]. Chinese cities are distinctive in their rapid development and in exhibiting widely varying development pathways, as well as in their disproportionate impacts on energy consumption and associated CO_2 emissions[76]. Many countries including China have attempted to apply integrating urban and transport infrastructure planning to provide their services more efficiently, with varying degrees of success. This includes facilitating modal shifts in transport by increasing mixed-use areas; efficient district heating planning and operation; and distributed electricity generation potentially coupled with a smarter demand. Decisions made in the next 10-20 years when a significant phase of urbanisation is expected to take place could have an enduring impact on energy use in Chinese cities.

In 2010, a number of low carbon pilot provinces and cities were announced, including the provinces of Guangdong, Liaoning, Hubei, Shaanxi and Yunnan, and the cities of Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, and Baoding. In addition, there is a growing trend of cities joining international initiatives in this respect (e.g. Beijing and Shanghai in the C40 Large Cities Climate Leadership Group, or Shenyang in the International Local Government for Sustainability Initiative). However, two notes of caution – the failure of the Dongtan low-carbon city to emerge, and the continuing urban sprawl in several major Chinese cities – should be remembered when considering these initiatives[77].

Conclusions

There are several feasible pathways for China to reduce greenhouse gas emissions to 2050 which are broadly consistent with a global goal of limiting global warming to 2° Celsius. However, a baseline scenario, in which China continues to be largely reliant on unabated coal for its energy supply and with energy efficiency improvements falling short of what could be possible even under business-as-usual assumptions, itself poses some major policy issues and challenges, in addition to the more-than-doubling of CO_2 emissions to 2050. The significant increase in coal demand can be questioned, not only on environmental and health grounds but also in relation to accessible coal reserves. This scenario also raises problems of high oil import dependency and higher levels of local environmental pollution, compared to the abatement scenarios.

The more aggressive abatement scenarios assessed here demonstrate how CO_2 emissions could be reduced to around 3 $GtCO_2$ by 2050 using a range of currently available, close-to-commercialisation, and in some cases known but commercially unproven (e.g. CCS) technologies. Such an abatement pathway could reduce coal demand to a quarter of the level in the baseline scenario and oil demand to less than half. Local environmental pollution would also be reduced. There are strong policy reasons for China to seek such a more environmentally friendly route and, indeed, this was the message of the Chinese Government in announcing its 12th Five Year Plan.

The largest part of the potential CO_2 savings in the Grantham Institute's abatement scenario comes from decarbonising the electricity sector. There is considerable uncertainty as to which low carbon power technologies will prove the most cost effective and continuing research, especially into CCS, solar PV and advanced nuclear technologies, is important. Meanwhile it makes sense to take advantage of China's wind, solar, and hydro resources, which are highly dispersed geographically and for which the development of a strong, smart, long distance grid will be essential to exploit them fully, as well as to balance intermittent and variable supply with new sources of demand.

Energy efficiency across the industry, transport and buildings sectors will also be critical to achieving a low carbon pathway to 2050. Energy efficiency, combined with decarbonised electricity, would lead to large reductions in fossil fuel demand at low or negative cost. However, as with other countries, the challenge is to develop the institutions and policies necessary to monitor, regulate, and incentivise these changes. International collaboration with developed countries with greater experience could be helpful in some of these areas, especially at regional and local levels. In addition, careful urban planning could have a big influence on vehicle ownership and use.

In the industry sector, CCS plays an important role in reducing CO_2 emissions. If China decides to adopt Coal to Liquids (CtL) technology on a large scale, CCS will also be needed to abate CtL emissions in the energy conversion sector. The demonstration of CCS in industrial processes on a commercial scale is therefore critical. In the transport sector, electric and hybrid vehicles make a big difference to oil demand and transport emissions towards the end of the period. The critical issues here will be the need for R&D to increase battery energy density and reduce cost, the development of charging infrastructure, and consumer preferences. In the buildings sector, aside from energy efficiency and decarbonised electricity, the widespread deployment of low carbon heating systems such as heat pumps and district CHP will drive emissions reductions.

As with the baseline scenario, China's abatement pathway presents a range of energy and resource considerations. Gas could represent an increasing element in China's energy mix in an abatement scenario, but there remain considerable challenges to securing gas supplies from abroad or accessing potentially significant unconventional gas resources, including their climate and local environmental impact. The question of whether, and to what extent, to develop the large coal reserves in China's far West is a major strategic decision for the Chinese government. This would require large scale investment in railways or electric transmission. The transmission option would give greater flexibility, for the future, to access lower carbon energy resources. And if China continues with its ambitious nuclear programme it will need to carefully consider its access to uranium supplies, or alternative technologies that would drastically reduce its uranium demand.

If China follows a carbon abatement pathway, its technology development initiatives and large market can be expected to have a major impact on the global development, including cost reduction, of key low carbon technologies, such as wind, solar PV, electric vehicles, nuclear power, and CCS. This may open up options that would not otherwise have existed for other countries. China may be a competitive source of supply and may also represent an export opportunity. China’s chosen pathway will also have a major impact on the international markets for fossil fuels.

There are several areas in which China could benefit from technologies and knowledge in the developed world. In general, Chinese capabilities are at this stage better in near-market technologies (for example onshore wind, in which it has gained a significant international competitive advantage)[78]. But in the case of more advanced and/or earlier-stage technologies such as advanced nuclear manufacturing, elements of solar PV and battery technology development, China still lacks advanced capabilities, and in such cases the acquisition of technology, manufacturing processes and know-how from other regions could be particularly important. International experience with urban planning for transport and buildings, and implementation of monitoring and regulation of energy efficiency standards for buildings and appliances, could also be useful to help successful implementation of China’s policies in these areas.

In addition, a number of technologies will only become commercially viable with specific policy interventions. Whilst China has implemented targeted policy interventions such as for example direct R&D and deployment support for onshore wind, there is in addition an increasingly apparent requirement for a long-term and stable carbon price to support several low-carbon technologies which will continues to be more expensive than their fossil-fuel based alternatives. China is now looking to develop and pilot domestic carbon trading schemes which could help do this.

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