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Carbon Emissions Scenarios for China to 2100

Tao Wang and Jim Watson

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Dr Tao Wang and Dr Jim Watson
Sussex Energy Group and Tyndall Centre
SPRU, University of Sussex, UK.

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[1] Contact: Sussex Energy Group, SPRU, Freeman Centre, University of Sussex, Brighton, UK, BN1 9QE; Email: tao.wang@sussex.ac.uk; Tel: +44 1273 877364.

Introduction

China's economy is growing rapidly with nearly 10% per year increases in GDP over the last two decades. At the same time the economic expansion is leading to large increases in energy demand despite continuously decline in energy intensity between 1980 and 2000. Since 2000, with quick expansion of heavy industries such as iron and steel, China's energy demand is rocketing with a reversed trend in energy intensity. Coal continues to dominate the Chinese energy system despite a slowly declining share, and is fuelling the majority of new power generation capacity. China's generation capacity has exceeded 700 GW in 2007, nearly 80% from coal. Demand for imported oil is also increasing sharply as car ownership rises and domestic oil output matures. China's oil import dependence is going to exceed 50% in 2010 compared with 29% in 2000. Demand for natural gas is also growing, and largely exceeds China's supply capacity.

These trends bring with them a number of pressing challenges. Securing enough energy to sustain economic growth is an important priority for the Chinese government. Alongside this, more attention is being given to addressing the environmental side effects of economic development. These include desertification, air and water pollutions. They also include an increasingly large contribution to international environmental problems, particularly climate change. China is now the world's largest emitter of carbon dioxide (CO_2), the most important greenhouse gas (GHG)[2], after a 50% increase between 2000 and 2005. Furthermore, some areas of China will be increasingly vulnerable to the impacts of climate change such as increased flooding and desertification. Aware of the huge challenges ahead, the Chinese government has set up various measures and target to reduce China's reliance on fossil fuels, particularly coal and mitigate the impacts of rapid economic growth. But effects of these measures are yet to be seen, and they are at the best only starters of what are needed to address China's environmental concerns and its implications to the international challenge of tackling climate change.

Against this background, the Tyndall Centre for Climate Change Research is conducting a research project on *China's Energy Transition: Strategies to Mitigate Carbon Lock-in*. The project began in August 2006 and will be completed in March 2009. The project aims to assess alternative energy futures for China, and to evaluate the scope for mitigating CO_2 emissions. A key question is whether China can avoid the problem of 'carbon lock-in' that is faced by most developed countries. This is characterised by dependence on carbon intensive energy systems and infrastructure that is difficult to change. The project is exploring a range of scenarios for China's future energy trends and carbon emissions, and aims to inform policy making in both China and the UK.

To date, the project has examined the unfolding energy transition in China through a historical analysis of energy supply and demand trends, and of policy and institutional developments. This initial research has also analysed available scenarios that explore potential future energy developments. It has considered scenarios developed by the Energy Research Institute (ERI) of the National Development and Reform Commission (NDRC) for China, and those by other international research groups.

This working paper summarises a new set of cumulative carbon emissions scenarios for China to 2050 and 2100 that have been developed within the project. These are based partly

[2] See http://www.mnp.nl/en/service/pressreleases/2007/20070622ChineseCO2emissionsinperspective.html

on methods that were developed by the Tyndall Centre to explore future carbon emissions in the UK (Mander et al.). The paper first summarises the results of some previous scenario exercises from both the UK and China. The second section of the paper explains the methodology that has been used for the new set of scenarios. The third section of the paper provides more details of the four scenarios that have been chosen, including the profile of emissions over time, and key quantitative and qualitative characteristics. Finally, preliminary conclusion and the next steps for the project are briefly outlined. The scenarios presented in this paper have been developed through a considerable process of dialogue with a range of organisations within China and the UK. Two workshops have been held to aid this process, one in the Beijing in 2007 and another one in London in 2008. Discussion on these two workshop have provided valuable insights from both Chinese and international experts on China's future development. We have incorporate most of them into our scenario building.

Some previous scenarios

Scenarios are now widely used to investigate potential future developments. Scenarios are neither predictions nor forecasts (IPCC, 2000). Scenarios are often used for the assessment of future developments that are either inherently unpredictable or highly uncertain. This usually means that a coherent set of scenarios is developed to explore the key dimensions of these uncertainties. Within this, each scenario describes and analyses just one possible future.

A large number of scenarios have been developed in recent years that are designed to explore future emissions in greenhouse gases, their potential impacts and abatement strategies. One of the most notable scenario exercises that has focused on climate change is the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) published in 2000 (IPCC, 2000). This includes four different narrative storylines that represent different demographic, social, economic, technological driving forces. Their environmental impacts are further developed to examine the range of outcomes for greenhouse gas emissions (IPCC, 2000). 40 SRES scenarios have been categorized in four large scenario families (known as A1, A2, B1 and B2). Many of the climate change and energy scenarios that have been developed since the publication of SRES are based these four scenario families.

There are a number of approaches to scenario building. Many scenario exercises start with the present day and then use simulation techniques, modelling or other forms of projection to develop a set of potential future trajectories or ‘storylines’. More recently, the increasing analysis of climate change has made it meaningful for some analysts to start with a desirable future state of the world such as a stabilisation target for greenhouse gas concentration in the atmosphere. The scenarios then work backwards from this future state using backcasting techniques to develop their storylines. The aim is to understand what range of developments and changes could occur that would achieve the desired future state.

Another distinguishing feature of different scenario sets is the extent to which they are based on a top-down or a bottom-up approach. Top-down approaches proceed from the general to the specific, starting with overview of the system, overarching principles, and then moving on to specific details. Bottom-up scenarios, on the other hand, start from specific details at the micro level, and aggregate these to build up a high level picture of overall trends. The choice of a top-down or bottom-up approach depends on the requirements of a particular scenario set.

A number of scenario exercises have explored potential long-term trends in energy and CO_2 emissions in China and the UK. This paper will describe three of these in detail. The first is the scenario analysis of China's energy demand to 2020 by the Chinese Energy Research Institute (ERI) in collaboration with the Lawrence Berkeley National Laboratory (LBNL) in the US using the LEAP 2000 model (hereafter ERI 2020). The second is a set of long term emission scenarios to 2050 developed by ERI using an Integrated Policy Assessment model for China (IPAC) (hereafter ERI 2050). The third is the set of scenarios developed for the Tyndall Centre *Decarbonising the UK* project which explore UK carbon emissions pathways to meet a government target of a 60% cut in carbon emissions by 2050 (Anderson et al.) The methodology outlined in this working paper was subsequently developed using a cumulative emissions approach in a further report on the UK: *Living Within a Carbon Budget* (Bows et al., 2006a). This employed a cumulative CO_2 emissions budget for the UK to generate two scenarios for the stabilisation of the global atmospheric CO_2 concentration at 450ppm (Anderson et al.). Table 1 lists the differences in approach among these three scenario exercises.

Table 1: Comparison of Scenario Analyses

	Main Objective	Timeline	Area	Direction	Approach
ERI / LBNL 2020	4x GDP with double energy demand by 2020	2020	China	Forecasting	bottom-up
ERI 2050	Develop low carbon energy system	2050	Global	Forecasting	both bottom-up and top-down
Decarbonising the UK	Reduce 60% UK CO2 emission from 2002	2050	UK	Backcasting	bottom-up with top-down target

As shown, the three scenario exercises encompass a variety of approaches. ERI 2020 has clear specifications on GDP growth but lacks firm targets for energy demand or CO_2 emissions. The ERI 2050 scenarios also forecast the future starting from the current situation without specific goal. Both of them are therefore based on forecasting methods. *Decarbonising the UK* on the other hand has clear target of a 60% cut in UK CO_2 emissions by 2050. It uses a backcasting approach to identify alternative pathways that arrive at this target. Both ERI 2020 and *Decarbonising the UK* use a regional, ‘bottom-up’ approach. ERI 2050 uses the IPAC model which combines both bottom-up and top-down approaches.

ERI / LBNL 2020

The ERI 2020 has three scenarios, which differ mainly on the extent to which the sustainable development policies are implemented, energy market is liberalised and adaptation to WTO and globalisation (Dai et al., 2004). Scenario A is the business as usual (BAU) scenario. Scenario B is a scenario with policies that are relatively successful in reducing emissions growth while scenario C is more ‘ideal’ and effective in reducing emissions. The three scenarios are not radically different from each other, but differ in the timing and depth of some common carbon mitigation and/or energy demand reduction policies applied to major sectors. The total energy demand in scenario C is about 30% less than that in scenario A while the middle-way scenario B includes only a 10% reduction from scenario A. The largest reductions come from the industry, transport and commercial sectors. The scenarios envisage a future in which power generating capacity in 2020 will be switched to more efficient and lower carbon energy sources, such as hydro, gas, nuclear, and renewables. Due to this shift in energy sources and reduction in energy demand, CO_2 emissions are lower than BAU in scenarios B and C, but not significantly.

ERI 2050

Using a more comprehensive integrated assessment model, ERI 2050 analyses potential trends in China to 2050. ERI 2050 primarily focuses on carbon emissions rather than energy demand but without a specific target. The ERI 2050 exercise includes a Policy and Technology (P&T) scenario with a more ambitious technology improvement and policy support than BAU. In the P&T scenario by 2050: applications of carbon capture and storage (CCS) will be nearly 3 times higher than BAU; clean coal technology will be used in 35% of power generation rather than 5% in BAU; the cost of renewable energy sources will be reduced quicker and become much more competitive due to energy tax and renewables subsidies. Energy efficiency will also experience rapid improvement, particularly from buildings and transport where fast growth is expected. The P&T scenario as a result leads to 27% lower primary energy demand in 2050 than BAU, but still more than 3 times the energy demand in 2000. Notably the demand for coal is significantly reduced to less than half of that in BAU. However, even in the P&T scenario fossil fuels still account for some two thirds of the total primary energy demand, as reflected in predictions by the International Energy Agency (IEA, 2006). Overall, CO_2 emissions in the P&T scenario are some 40% lower than in the BAU scenario or 1263 MtC[3] less in 2050. This scenario exercise pays particular attention to cleaner coal technology development and policy support to accelerate the deployment of low carbon options in China. It concludes that sustainable energy policy is needed that provides economic incentives to reduce energy demand, incentives to stimulate R&D in new technologies and investment in renewable energy sources.

Decarbonising the UK

The *Decarbonising the UK* scenarios are a major output from the Tyndall Centre's first five year phase of work, conducted between 2000 and 2005. The scenarios explored a wide range of technical, management and behavioural options for realising a 60% reduction target in CO_2 emissions in the UK by 2050 (Anderson et al.). Various scenarios were designed against different assumptions for energy supply, energy demand, efficiency improvement and sectoral changes. The scenarios use backcasting to comply with the desired target, but several intermediate targets were also incorporated including: meeting the UK's target under the Kyoto Protocol of a 12.5% reduction in greenhouse gas emissions by 2008-2012 compared by the 1990 level; a 20% reduction in domestic CO_2 emissions by 2010 compared with the 1990 level; and 10% electricity from renewables by 2010, 15% by 2015 and 20% by 2020.

Five scenarios were designed, each with a different set of supply, demand, innovation, efficiency and growth characteristics (Anderson et al.). Each scenario included the UK's contribution to international aviation and shipping emissions – sources that are not currently included in official inventories. They were named after colours to minimise any impression that value judgements had been made about their relative desirability: high economic growth with low energy demand (Red); modest (Blue) or medium (Turquoise) growth in both economic output and energy demand; and high growth in both economic output and energy demand with nuclear dominating energy supply (Purple) or a more diverse supply mix (Pink). The differences in the scenarios are large. For example, the economy in 2050 under the Red

[3] MtC is million tonnes of carbon.

scenario is about 2.5 times large as that under the Blue scenario, but it consumes less than 70% of the energy consumed under the Blue scenario. The Purple/Pink scenarios include a similar economy size to the Red scenario, but their energy consumption is almost 3 times larger. Several key messages were then delivered from the scenario analysis.

- Meeting the target of a 60% reduction will be difficult, especially when including international aviation and shipping
- Efficiency improvements can make a large contribution to decarbonising the UK
- The target can be met either by reducing energy intensity, or through reduced carbon intensity of energy in a high energy demand future
- Energy demand reduction could offer more flexibility than low carbon energy supply options, since the latter is likely to bring with it major infrastructure challenges

Our scenario approach

Having summarised some previous scenarios for both China and the UK, the paper will now show how the new Tyndall Centre scenarios for China have been developed so far. Some features of the previous scenarios discussed above have been used to inform the development process. An important decision early on has been to use backcasting to generate the new scenarios. However, instead of using a percentage reduction target such as the 60% used for *Decarbonising the UK*, the new scenarios have chosen to select a cumulative emissions budget. This is the method that was used for *Living Within a Carbon Budget*, the successor study to *Decarbonising the UK*.

Having chosen budgets for China to live within, this section will show how a number of possible emissions pathways have been chosen for the period from now to 2100. Of course, these do not describe all possibilities – but are designed to help explore some key dimensions that have been raised in our workshop discussions. Each pathway has an associated storyline that describes trends in technologies, governance and behaviours that affect the main energy consuming sectors of the economy (households, transport, power generation and industry). It is important to note that we have adhered to a basic principle of scenario development in generating these pathways and storylines: no judgement is made about the most desirable or likely scenario.

Choosing a global budget

Since CO_2 stays in the atmosphere for more than 100 years, emissions from many decades ago will have a similar impact on the climate as emissions today. Therefore it is reasonable to investigate the consequences of limiting *cumulative emissions* of CO_2 over time rather than simply analysing specific percentage cuts in emissions by specific dates (Anderson et al.). As noted earlier, this approach has already been used by the Tyndall Centre in its most recent scenarios for the UK (Bows et al., 2006b).

Following on from this, our project is analysing China's cumulative emissions of CO_2 over the 21^{st} century. We have decided to choose a cumulative emissions budget for China that is commensurate with a target for the stabilisation of CO_2 concentration from the IPPC Fourth Assessment Report (AR4) Working Group 1 (IPCC, 2007b). This stated that global cumulative emissions for this century should be no more than **490GtC** (gigatonnes of carbon) in order to stabilise the CO_2 concentration at 450 ppm. Given the assumptions for other greenhouse gases in the IPCC report, this is equivalent to a concentration for all greenhouse gases of around 550 ppm CO_2 equivalent (CO_2e) (IPCC, 2007a). The IPCC stated that these concentrations would be likely to result in a global average temperature rise in the range 1.9-

4.4°C above pre-industrial levels, with a central estimate of 2.9°C (IPCC, 2007b). This stabilisation level is more or less the upper level that is recommended in the Stern review (Stern 2006) between 450-550 ppm CO_2e, but higher than 500 ppm CO_2e that he suggested June this year[4]. However, either of them would require much more than the current target of 60% emission reduction by 2050 that UK government proposed in Climate Change Bill, or a gradual 2.5–3% emission reduction per year that is suggested by the Stern Review and Defra (Anderson et al.).

Of course, there are other options that we could have used as well as other interpretations of specific concentration targets. This IPCC projection has a high change of pushing global temperatures above 2°C. Many argue temperature increases above this level are much more likely to lead to more serious, irreversible impacts[5]. To have a much higher probability of confining temperature increases to 2°C, a smaller global cumulative emissions budget would be necessary. For example, Meinshausen predicted the world could emit around 400GtC in this century with about 50% probability of an average temperature rise of over 2°C. This would mean stabilisation of the concentration of greenhouse gases in the atmosphere at 450 ppm CO_2e in 2100 (Meinshausen, 2007). In an earlier prediction, Meinshausen stated that even lower cumulative emissions over this century of 387GtC would lead to a less than 30% probability that global average temperatures will overshoot 2°C. In this second case, the concentration of greenhouse gases would peak at around 475 ppm CO_2e before stabilising at 400 ppm CO_2e (Meinshausen, 2005).

The problem with these lower budgets is that they make it more difficult to develop a plausible global emissions pathway. Within this, pathways for individual countries including China can be very challenging. For example, the rates of decrease in emissions would either have to be very high (with emissions beginning to fall very soon) – or alternatively, China would need to be allocated a very large share of global cumulative emissions. For this reason, we have chosen a larger global emissions budget that has a higher chance of causing severe impacts – and it should be recognised that adaptation to these impacts will be much more important than under scenarios in which global emissions are more constrained. As this paper will go on to show, the possible pathways for China's emissions under this larger global budget are still challenging.

Which apportionment method?

Although the latest report from the IPCC analyses cumulative emissions (Intergovernmental Panel on Climate Change, 2007), there is no consensus on the appropriate way to apportion these emissions between different countries. This is one of the most controversial issues in political discussions about greenhouse gas mitigation, particularly with respect to possible 'post 2012' international regimes (Böhringer and Welsch, 2006). There has been significant discussion in the climate change literature of different approaches to this question (Rose and Stevens, 1993; Grubb, 1995; Ridgley, 1996; Rose et al., 1998; Gupta and Bhandari, 1999; Metz, 2000; Leimbach, 2003). Four of these are briefly discussed here: the equalisation of per capita emissions; the equalisation of emissions per unit of GDP; apportionment based on historical responsibility; and grandfathering.

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[4] See http://www.guardian.co.uk/environment/2008/jun/26/climatechange.scienceofclimatechange?gusrc=rss&feed=environment

[5] See for example, policy statements from the European Commission. See (European Commssion, 2007)

The equal emissions per capita approach has been developed using the concept of Contraction and Convergence (C&C) by the Global Commons Institute. Its basic principle is that each person in the world should be entitled to the same level of carbon emissions. Under this approach, emissions in many developing countries would be allowed to rise from current levels whilst all developed countries would need to reduce emissions. Some have pointed out that this approach is not as equitable as it seems since it fails to address different personal needs that are associated with existing natural and cultural living conditions (Leimbach, 2003).

The second approach focuses more on global economic welfare and growth. It aims to equalise carbon emissions per unit of GDP in different countries. This emphasises carbon efficiency and would provide a strong motivation for countries to try to decouple economic growth and carbon emissions. However, it provides developed countries with some advantages since they have a better starting point. For some, this is "equivalent to penalising the developing for their later progress" (Rose, 1992). Gupta and Bhandari (1999) have proposed an approach that tries to combine the per capita and carbon intensity approaches

Due to the long lifetime of CO_2 emissions in the atmosphere, others have suggested approaches that take historical emissions into account (Winkler et al., 2002). Under this method, those countries that are the most responsible for the loss of atmospheric assimilative capacity would contribute most to future reductions in emissions. The drawback with this is that there are many possible starting points for historic emissions. The choice of starting year for the calculation of emissions will influence how future reductions are shared between countries. This could be 100 years or more ago (to reflect the residence time of CO2 in the atmosphere) or as recently as 1992, the year of the Rio Earth Summit and the start of IPCC greenhouse gas inventories (Rive et al., 2006).

A further alternative is to use grandfathering to allocate emissions (Rose et al., 1998; Miketa and Schrattenholzer, 2006). This would allocate responsibility for future reductions in emissions in proportion to each country's current emissions. This would not take ability to pay into account, and could be particularly difficult for developing countries since absolute reductions would be required (Böhringer and Welsch, 2006). It has been proposed that grandfathering could be modified to take ability to pay and historical responsibility into account. However, this can still lead to challenging targets for some developing countries.

We have decided to use both of the first two apportionment approaches within our scenarios to calculate China's cumulative emissions budgets for the 21st Century. It is worth noting that we do not expect actual emissions to conform to these budgets. We have simply used them as a way of generating a distinctive range of cumulative budgets for China which will have significantly different implications. As shown below, budgets for China that are generated using per capita emissions convergence are much smaller than budgets that converge at an equal level of emissions per unit of GDP. The way in which we have applied each of these is as follows:

1. Contraction and convergence (C&C) based on equal carbon emissions per capita is used to generate budgets for two of our four scenarios. Under this approach, global emissions per capita will converge by 2050. Following this, emissions will reduce at the same rate to meet the stabilisation target for the end of the century. Relative changes in population in different countries after 2050 will not affect national shares of global emissions.

2. Contraction and convergence (C&C) based on equal carbon emissions intensity of GDP, using Purchasing Power Parity (PPP) is used for the other two scenarios. This approach is similar to the first one, but instead of having equal emission per capita in 2050, countries will converge at the same level of carbon emissions per unit of GDP (PPP). Then emissions will reduce at the same rate globally to the stabilisation emission level. Similarly, relative changes in GDP growth in different countries after 2050 will have no impact on each nation's share.

The global shares of cumulative emission for some major countries in the 21st century under the two different apportionment approaches are shown in Figure 1.

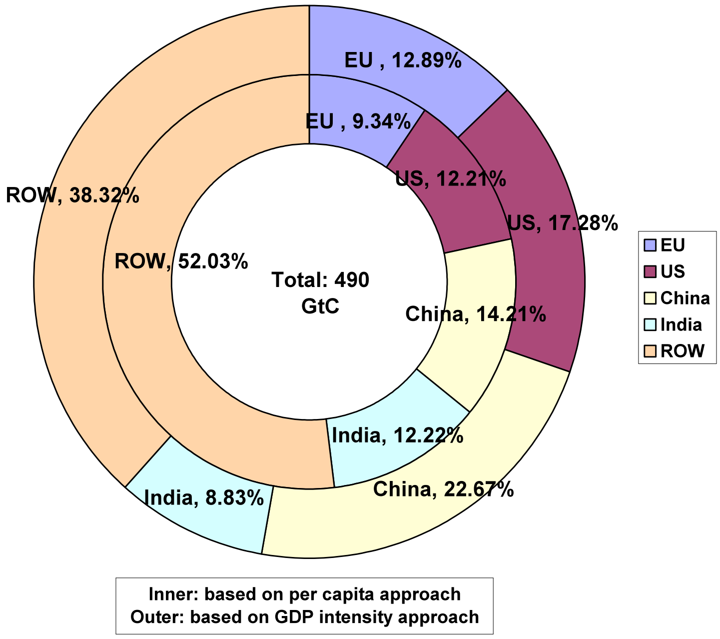

Figure 1: Shares of cumulative emission under two approaches

Cumulative emissions budgets for China

It is clear that the two critical factors that will determine China's cumulative emission budget within this analysis are the relative growth rates of population and GDP.

Within all scenarios, the population growth of China in the four scenarios follows the median population projections from the United Nations (UN 2004). These state that China's population will slowly increase at around 0.4% p.a. from 1.3 billion in 2003 to 1.44 billion in 2030 before declining. China's population will be overtaken by India around 2035, whose population increases twice as fast between 2000 and 2050. In 2050, China's population will be around 1.4 bn while India has the largest population of the world of 1.5 billion. The world's population is nearly 9 billion in 2050. Using these figures and the global cumulative emissions budget from earlier gives a budget for China of **70GtC** over the 21st Century.

The GDP data used in this research is based on a purchasing power parity (PPP) approach. This equalises the carbon impact of each country's generation of economic wealth by taking into account differences in purchasing power in different countries. Using this data, the global emissions budget is then allocated to each country based on the carbon emissions intensity of their economy. The current national data of GDP PPP is taken from the World

Development Indicators 2006 (World Bank 2006). Predictions of economic growth are based on estimates from the International Energy Agency (IEA)'s World Energy Outlook 2006 for 2003-2030, and from the IEA's Energy Technology Perspectives 2006 for 2030-2050. Note that GDP growth is only fixed using this data to generate China's cumulative emission budget. The actual rates of GDP growth will be allowed to vary within each scenario when it comes to elaborating the pathway of emissions over time (see below). Using these assumptions gives a cumulative emissions budget for China of **111GtC** for the 21st Century.

From budgets to trajectories

Whilst these two methods have provided two distinct carbon budgets for China, the scenario development process still includes significant room for manoeuvre. The pathway taken by China's annual emissions over time is fully flexible as long as the cumulative emissions budget is not exceeded and the annual emissions in 2100 are the same as the annual emission at stabilisation. In another words, the two apportionment approaches that have been chosen do not completely constrain China's actual emission pathways over time. This provides significant scope for scenarios that reflect different assumptions about economic development, energy use and emissions.

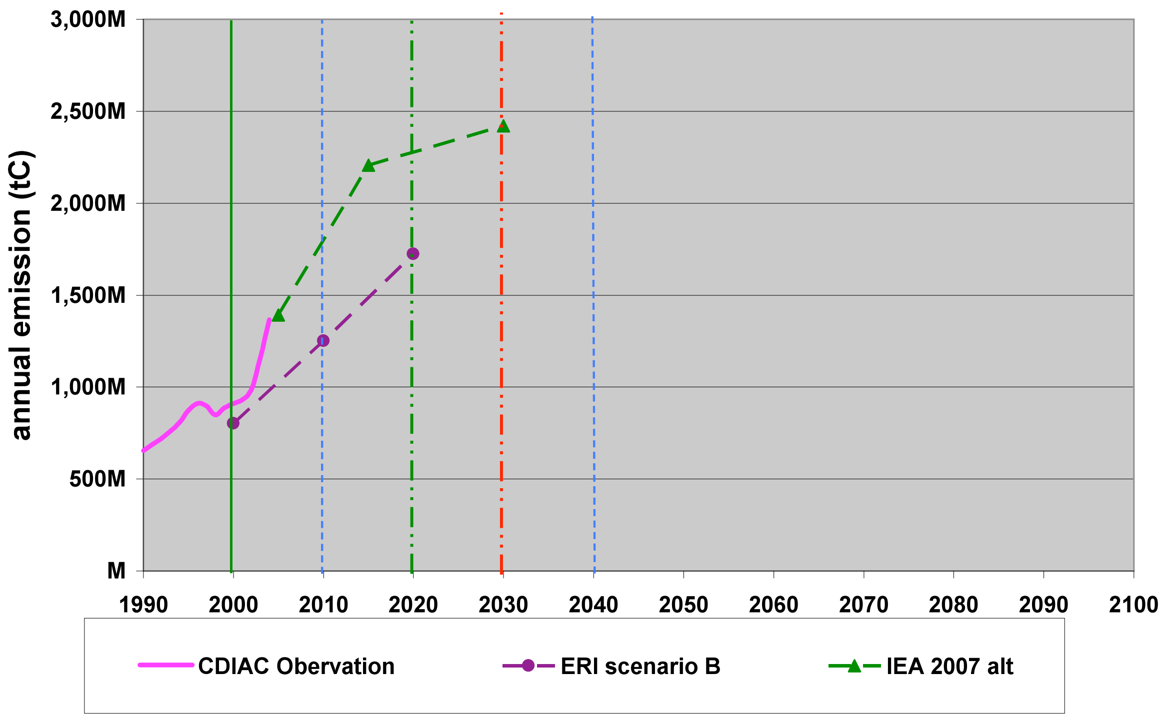

Figure 2: Carbon emissions in China since 1990 and projections by IEA and ERI

The next step in the scenario development process is to outline four carbon emission pathways over time using these two budgets. Following discussions at our second workshop, our approach has been to consider medium-term emissions pathways that have already been put forward by Chinese and international policy processes as first steps towards decarbonisation in China. Our analysis will then see whether these pathways are compatible with the carbon budgets for the entire century that were outlined above. The two medium-term pathways we have chosen are the International Energy Agency's alternative scenario from 2007 and the Chinese Energy Research Institute's scenario B. The latter pathway incorporates an official Chinese government target that the size of the economy could be quadrupled between 2000 and 2020, whist energy demand doubles. Each of these two pathways can be combined with both of our cumulative budgets to yield a total of four scenarios. The two medium-term pathways are illustrated in Figure 2 along with China's historical emissions since 1990.

The IEA's alternative scenario (IEA, 2007) for China takes into account the energy and climate related policies that are and have been considered by Chinese government. This scenario "*illustrates how far policies currently under discussion could take us and assesses their costs*" (IEA, 2006`, page 49). However, the pathway described by this alternative scenario doesn't show a dramatic change in China's rate of carbon emissions growth during the next two decades. We have therefore used this pathway to illustrate the impact of relatively incremental changes in China's economy and energy system to 2020.

The basis for our second medium term pathway, ERI's scenario B, was described as "a detailed interpretation of the sustainable economic and energy development for the 10th Five-Year Plan and the following 10 years" (Dai et al., 2004`, page VII). Other scenarios were summarised earlier in this paper (Dai et al., 2004). However, when these scenarios were produced in 2004, they did not anticipate the sudden surge of China's energy demand and carbon emissions since 2000. This has occurred as a result rapid growth in industrial sectors and a structural shift within industrial sub-sectors towards heavy industries such as steel and cement (Lin et al., 2008). As a result, the 2010 estimate for carbon emissions within this scenario was exceeded in 2004. Another issue is that the data used in this scenario for 2000 was slightly lower than the historical CDIAC data we have used in our analysis. However, despite these shortcomings, we have used their emissions estimate for 2020 to derive a medium-term pathway that illustrates a rapid and significant change in China's industrial and economic structure. This is a feature that participants in our first workshop in Beijing were particularly keen to explore. It assumes a reduction in the share of heavy industry in China's economic growth and therefore reduces overall energy intensity. The resulting medium term pathway is in line with the Chinese government's short-term target of reducing energy intensity by 20% by 2010 and its medium-term target of quadrupling the size of the economy whilst only doubling energy demand between 2000 and 2020.

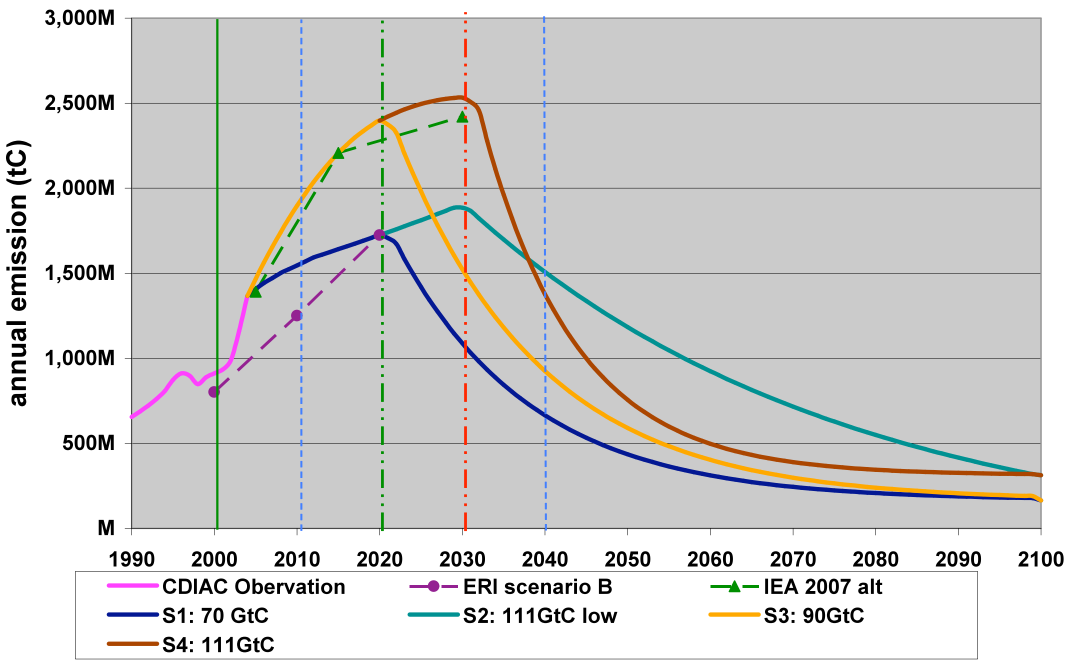

Figure 3: Carbon emissions in China: Historic data, projections and Tyndall scenarios

For both of these medium-term pathways, the trajectory of China's carbon emissions starts from CDIAC data for the period 1990-2004. These two pathways are followed until 2020 at which point each divides into a further two pathways – giving us our four scenarios. All four pathways are shown in Figure 3.

Before describing each individual scenario pathway in more detail, it is worth commenting on some of the choices that have been made here. First, the medium-term pathways have only been followed to 2020. This maximises the chance that the scenarios will remain within their carbon budgets.

A second point is that each scenario includes a peak in emissions followed by a decline to remain within its carbon budget. The peaking years are between 2020 and 2030 in order to balance practicability and flexibility. A peak earlier is thought to be unfeasible while a peak later would make it too difficult to remain within the cumulative emission budgets that we have chosen. Even this range of turning points necessitated some adjustment to our carbon budgets. In the case of the high emission medium-term pathway described by the IEA, it was not possible to follow this pathway and stay within the smaller 70GtC cumulative budget for the whole century due to the large emission accumulated before reaching the peak. We therefore increased the budget in this scenario to a slightly higher level of 90 GtC just to make sure the scenario could still be feasible. The stabilisation level at end of the century remains unchanged. Sitting midway in the range between 70 and 111GtC, the additional emission budget under this scenario could imply a possibility of delayed international climate agreement, or delayed action to curb its carbon emission due to the incremental process.

A third point to note is that each scenario follows a declining emissions trajectory towards 2100 following the emissions peak. This decline is designed so that the pathway is consistent with the scenario's cumulative emission budget. The rate of decline for each is determined by how much of the budget has been used before the peak.

The Tyndall China scenarios in detail

Having set out the important features of each scenario's carbon emissions pathway, it is important to provide some more information on these pathways. This will aid our detailed elaboration of the pathways, and the way in which annual emissions from different sectors of China's economy will fit within the overall trajectory described in each case. Tables 2 and 3 summarise the key features of each scenario – both in general and with respect to the energy systems described within them. Following these Tables, a narrative storyline is provided for each scenario which gives some further information about key trends.

Table 2 describes the basic features of each scenario, including the cumulative emissions budget, the medium-term pathway that it includes and the year at which emissions would peak. It then includes a range of rates of GDP growth which will be applied throughout the scenario period and confirms a uniform assumption about population growth – something that clearly needs to be borne in mind when interpreting the scenarios. The Table then describes some of the anticipated changes in China's economic and industrial structure in each scenario. These are features which were seen as critical drivers of China's medium and long term energy demand and emissions in both of our consultative workshops.

Table 2: General characteristics of scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Cumulative budget	70GtC	111GtC	90GtC	111GtC
Medium-term pathway	ERI	ERI	IEA	IEA
Year of emissions peak	2020	2030	2020	2030
GDP growth rate	2-4%	5-8%	4-6%	2-8%
Population growth rate	Same in all scenarios following the UN 2004 prediction			
Economic Structure	• Service sector dominates • Weak industry; • Small but dynamic agriculture	• Moderate service sector • Strong industrial sectors • Small agriculture	• Service sector is largest • Strong industry • Moderate agriculture	• Both service and industrial sectors are strong • Small agricultural sector
Industrial structure	Moderate size of innovative industry ; traditional manufacturing is small	Large innovative industry; traditional manufacturing is small	Strong manufacturing industries; significant new innovative industry	Strong manufacturing; small innovative industry
Nature of innovation	Highly innovative, tendency for radical technical change	Strong science and technology advance; but slower diffusion	Significant technical change – cumulative, incremental process	Incremental innovation, mainly in legacy industries
Openness of economy	Outward looking, but special treatment for domestic industry	Globalised and outward looking	Globalised and outward looking	Continued globalised, export-led growth

The information about these economic and industrial trends – and related features such as the openness of the economy and the nature of innovation – merit some further explanation. We have used these features to explore the possible implications of current efforts to rebalance the sources of China's economic growth (Wen, 2008). As Nicholas Lardy has pointed out, China's recent growth has been driven by a large, growing trade surplus and rising investment (Lardy, 2007). One effect of this has been disproportionate growth in energy demand and emissions because of the relative importance of investment in energy-intensive sectors such as coal, steel, cement and chemicals. He argues that whilst Chinese government policy is to rebalance the pattern so that domestic consumption (and hence the production of consumer goods) become more important, these policies have had a limited impact so far. Against this background, scenarios 1 and 2 describe futures in which rebalancing has been more successful and more rapid – whilst scenarios 3 and 4 assume that this process has been slower and less successful. The first two scenarios are characterised by more radical change, and more pronounced shift away from traditional heavy industries towards more value added manufacturing (denoted 'innovative industry' in the Table) and the provision of services.

Table 3 provides more specific details of the direction of energy system development in each scenario. It includes details of energy demand, priorities for primary energy supply, and priorities for power generation. Energy sources are ranked in order of priority at this stage. Details of their actual contribution at different times and their rates of growth (or decline) will emerge as the quantification of the scenarios progresses. The Table also includes some details about the likely evolution of specific energy technologies in each scenario. Change in fast growing sectors such as households and transportation are given special attention in our scenarios as they are likely contribute significantly to the increase in energy demand in the future. For this reason, the Table includes information about likely changes in the efficiency of energy use, citizens' behaviour, and the organisation and efficiency of transport and housing.

Table 3. Energy system characteristics of scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Energy demand (relative to recent)	Slow growth	Moderate growth	Moderate growth	High growth
Primary energy supply mix (in priority order)	renewables; fossil fuels or nuclear;	renewables; fossil fuels;	nuclear; fossil fuels; renewables;	fossil fuels; nuclear; renewables
Power generation (in priority order)	renewables; coal with CCS or nuclear;	renewables; large hydro; coal and gas with CCS;	nuclear; coal with CCS; renewables	coal and gas with CCS; nuclear; renewables
Energy technology deployment:				
Energy consumption and behaviour	Stringent energy efficiency standards; early and quick behaviour change	Moderate standards to reduce consumption; slower change in behaviour and consumption than in scenario 1	Slow improvements in efficiency; significant behaviour change through education and incentives	Incremental improvements in efficiency (quicker than scenario 3); slow behaviour and lifestyle change
Clean coal and CCS	Moderately important / urgent	Not urgent; gradual diffusion	Very important and urgent	Important but slow diffusion at first
Wind and solar	Moderately important	High importance / quick diffusion	Moderately important	Moderately important
Biomass	High	Moderate	high	low
Hydro	High	moderate	high	moderate
Transport, housing and urban development:				
Average house size	small	medium	large	medium
Housing density	High density in large cities; population more dispersed in smaller towns and cities	Medium density in large cities; continuing migration from rural areas to large cities	Moderate density in large cities; population more dispersed in smaller towns and cities	Medium density in large cities; continuing migration from rural areas to large cities
Transport System	Public transport prioritised - highly efficient with wide coverage	High mobility demand with large public and private transport use. Low carbon technologies extensive	Large public transport system; incremental deployment of low carbon technologies	High mobility demand met through public and private transport; slow diffusion of low carbon technologies
Private car ownership	Low	High	Moderate	High

Scenario 1: 70GtC 2020

Highly innovative; service dominance; social equity strong; domestic driven economy

This scenario has the smallest cumulative emissions budget for China. Due the per capita method used for emissions allocation and the low figure for cumulative emissions, society in this scenario would give more priority to social equity and welfare improvement. This would be manifested in various ways such as healthcare, education and public safety, while placing less emphasis on economic efficiency and wealth accumulation. Average rates of economic growth in this scenario are very low in comparison with recent trends. China's carbon emissions will peak in 2020 and then reduce to comply with the small emissions budget. Society is highly innovative because of a strong promotion and pursuit of science and technology advances. Service sectors become dominant in the economy as people shift consumption quickly from purchasing physical goods to buying more services such as education and holidays. Society is quite stable and harmonised with reduced disparities of wealth and significant social welfare coverage.

Energy and power generation

In this scenario, energy and power will be supplied from a wide range of sources, with the largest share from renewables, and followed by fossil fuels or nuclear. The precise order of priority within this scenario will become clearer as the more detailed analysis progresses.

Because of the pressure of emission reduction, the use of coal across the economy will be gradually reduced and will increasingly be burned with advanced technologies. Renewable energy sources, natural gas and nuclear power will increase their shares of energy supply. Oil will still be important for transport (see below), but demand will increasingly be moderated by efficiency gains, modal shifts and new technologies. In addition, overall energy demand growth will be much lower than it has been in recent years due to increasingly stringent efficiency measures.

In power generation, coal will still have largest share by 2020. Energy efficiency will have improved significantly, with replacement of small inefficient plants with more advanced ones. CCS technology will be proven and less costly by 2020, and it will therefore be feasible for it to be compulsory after this date. After 2020, power generation from renewables (including some large hydro), natural gas and nuclear power will account for incremental increases in capacity and will also replace coal-fired capacity. Older coal-fired capacity that remains will be retrofitted with CCS where feasible. Power generation from natural gas will be facilitated by more availability of natural gas from domestic and imported sources.

Renewables will eventually become the largest source of power generation – and overall energy supply. Among the renewables energy sources, a large proportion of the renewables are from biomass and small hydro, benefiting from changes in agriculture sector. Wind power becomes another significant energy source assisted by technology advances and public support. PV has increased a lot but still only provides a small proportion of electricity. Solar thermal for hot water and some heating is more significant. Renewables diffusion is accelerated by both financial incentives and technical progress. Some renewable technologies will become more economic than coal. As a result, this has the most decentralised power system. Decentralisation also encompasses the provision of heat with widespread use of fossil and renewable combined heat and power (CHP) for urban areas; while demand in rural areas includes significant amounts of biogas and solar thermal.

Industry and services sectors

China will pass the phase of heavy industrialisation very quickly in this scenario. By 2030, energy and resource intensive industries are much smaller than they are at present, but will still persist at a significant level mainly to provide domestic needs. Improvement in energy efficiency and new materials technology make heavy industries much more efficient and sustainable than today. With strong support and promotion in innovation and technology transfer, high technology and high value-added industries become dominant. The overall share of industry is smaller whilst services have the largest share of economy, contributing 60-70% of the GDP. Together with reduced emissions from industry and agriculture, overall energy demand growth from Chinese economy is slow. A flourishing service sector offers wide and in-depth coverage to people's living and welfare support. Energy service companies grow particularly fast to offer both supply and demand side management.

Households and personal transport

Energy demand in household and personal transport will increase due to the higher income and living standards, but at a relatively low rate because people in this scenario have strong preference for environmentally friendly housing and public transport. Environmental education and awareness will trigger behaviour and consumption changes in early years and make people more inclined towards a green lifestyle. People start shifting more consumption from material goods to services before 2020.

New buildings are compliant to high energy efficiency standards and maximise the integration of natural lighting and renewable energy sources for heating and power. Solar heating is the major heating system supplemented by other sources including fossil fuels and biomass. Old houses and flats are gradually upgraded to a similar level. Private car ownership has increased moderately but energy efficiency and alternative fuels are able to largely offset the increased emissions from this. People use more public transport particularly in cities and towns while in rural area private transport is run on energy efficient and low carbon fuels. Similarly, demand for international aviation and shipping are also reduced to a low level in this scenario. Despite these changes, households and transport will become bigger sources of emissions than industry sometime after 2030.

Scenario 2: 111GtC 2030L

Innovation driven, strong high tech industry; economic growth; globalised economy

This scenario has similar development path to scenario 1 until 2020, but its overall emissions budget is larger since it is allocated via GDP emissions intensity instead of per capita. This is an approach in favour of economic efficiency and high GDP growth – leading to moderate energy demand growth. This larger budget also allows the scenario to include emissions growth for a further 10 years before the peak in 2030. Due to the early transition away from heavy industry, the peak of emissions is relatively low, compared with that in scenario 4. The economy in this scenario is globalised and industries are more exposed to global competition and also more reliant on global demand than for scenario 1. Social equity is improved but income disparity is larger than in scenario 1 as a result of more focus on economic efficiency. Government is still active in the provision of welfare systems, such as healthcare, education and insurance as private actors are less willing to deliver these services. The service sector is still the largest sector of the economy despite a strong manufacturing industry.

Energy and Power mix
In this scenario, renewable energy, especially wind and solar PV, will develop quickly and will become the largest source of energy in general – and power generation in particular - after 2030. With strong international financial and technology support and transfer, the cost of many renewables becomes competitive with fossil fuels from 2020. In transport and heating, fossil fuels remain important, but become less so beyond 2030 due to a combination of efficiency and the deployment of renewable technologies.

The second largest source of electricity is large hydro, which is more controversial in an international context and hence develops less quickly than other renewable options. With a relatively large carbon emission budget in this scenario, nuclear doesn't appear to be attractive for large up-scaling because the benefit from carbon saving does not overweigh its potential risks. Power generation from coal and gas is thought to be more feasible – particularly once CCS technology is proven in the late 2010s. CCS will be implemented more slowly than in scenario 1 and only diffuse gradually. This is because there is less stringent pressure to cut emissions beyond 2020 than in scenario 1, but also due to the concerns about the cost and the impact of this on international competitiveness. To cope with larger energy demand from industry, old coal fired power plants are replaced by new advanced plants, leading to much larger power generation capacity. Decentralised electricity and heat generation through renewables and fossil-fuel combined heat and power will provide most household energy needs, though central electricity generation will still be important.

Industry and services sectors

China's industrial structure in this scenario will be very different to now in 2020. In a globalised economy in this scenario, industry will respond actively to demand from both domestic and international markets. Therefore, they will have a larger share in the economy than in scenario 1. Chinese industry will transition quickly from dominance by traditional heavy industry to highly innovative, high technology industries. These new industries will make a strong contribution to GDP and become new engine of economic growth. Conventional industries persist in the new industrial structure as energy efficiency and material use have helped to reduce their impact on carbon emissions and the environment. Energy management services are in widespread use, from primary energy providers to end users, as regulation requires. The government is a significant player in energy investment, via both regulation and R&D support, especially for long term investment in advanced technologies. Service sectors are not as developed as in scenario 1, but they still comprise the largest share of the Chinese economy.

Households and personal transport
Overall emissions from households and private transport increase rapidly to 2030 and plateau afterwards. Household energy consumption and associated carbon emissions will increase largely due to the higher income and living standards. This will be partially offset by improved efficiency due to new, innovative technology applications diffused through the application of stronger standards. Housing will be built to a higher level of energy and material efficiency than today. Micro generation and other decentralised sources will provide a significant share of household energy consumption, but the centralised supply system will still be very important. Public transport is well networked and operated in most cities. Although private transport is still an important and widely adopted means of travelling, vehicle and fuel technologies have made it more environmental friendly. Biofuels and electric vehicles will be very popular and contribute significantly to emission reductions by 2030. After 2030, more radical transport technologies and infrastructures such as hydrogen fuel cells and advanced biofuels will cut emissions substantially. Due to a high demand for mobility, international aviation and shipping will increase quickly. Environmental education and awareness-raising will make people choose more green options but the impact is initially blunted by the rate of increase in consumption, and only becomes significant after 2030.

Scenario 3: 90GtC 2020

Service dominated economy; strong manufacturing industry; social equity and welfare; global and domestic driven

This is an economy that is globalised, but with some more focus on domestic consumption. The economic growth rate in this scenario is lower than it has been recently, because of this renewed local focus and a continued reliance on conventional manufacturing industries. The supply of energy and other resources act as constraints in this scenario. China's carbon emissions will peak at around 2020 and will have to undertake a quick reduction to remain within a challenging cumulative emission budget. Government emphasises social equity and the fair distribution of wealth. Social welfare is given more priority than economic expansion, resulting in a strong social welfare system supported by both public and private sectors. Service sectors are well developed and contribute the most to GDP. The society is stable and equal but less dynamic due to a conventional economic growth path. Innovations in this scenario tend to be incremental rather than radical changes due to lack of large investment and a more pragmatic society. Government is not so efficient with relatively high transaction costs. Efforts to promote adaptation to climate change are high in agenda and form an important part of broader social services provided to communities.

Energy and Power mix
A unique feature of energy and power mix in this scenario is the big role nuclear power plays. With less technology advances and lower level of international collaboration, renewables will take more time to become technologically and economically viable. As with other scenarios, oil remains important for transport in the short and medium terms, but is replaced as the need to reduce carbon emissions quickly becomes apparent after 2020.

Nuclear becomes a favourable choice for medium term emissions reductions from the power sector – and fits with a continuation of a centralised model of energy production and a desire to reduce the dominance of coal. Coal fired power plants are still very important in this scenario. Cleaner coal technology is given a high priority to make short term emissions reductions with technologies including ultra-supercritical coal and some IGCC being deployed. CCS is regarded as increasingly urgent, and becomes mandatory in 2020 – and is rolled out for older power plants when feasible after that date. Some large-scale fossil fuel power generation is also used to generate heat for industry and some households.

In this scenario, renewable power generation is slow to develop. Wind and solar PV only have small shares by 2030 for technological and cost reasons. Small hydro and some biomass are deployed in areas where these resources are widely available – particularly in rural areas. Some progress is made in micro-generation to generate electricity and heat for households, but this is supplementary to the dominant centralised mode of provision.

Industry and services sectors
In this scenario, Chinese industry will respond to a combination of domestic consumption and international markets – with some rebalancing in evidence. Exports will plateau by 2015 and start declining after losing cost competitiveness. But industry will still be boosted by domestic demand from ongoing economic growth. The industrial sector will include a fair share of high technology industries, but conventional manufacturing industry will still maintain dominance. Incremental energy efficiency and material improvements will reduce the overall carbon and energy intensity of industry but slower than in scenarios 1 and 2. The share of industry in the national economy will reduce, and take second place to a growing services sector. The service sector has the largest share of economy, contributing around 70% of the GDP.

Households and personal transport
Energy demand from households and the transport system increases moderately in this scenario. These sectors replace industry to become the greatest sources of emissions after 2030. As demand increases with disposable income, a shift to more service-based consumption after 2020 will slow down the increase of carbon emissions from households. Energy efficiency improvements will contribute to emission reduction but not as much in the first two scenarios. Both old and new buildings are required to comply with energy efficiency standards and there is significant use of natural lighting and renewable energy when economic. Solar heating is important for hot water and heating, with important roles for gas and electricity. Micro- and decentralised energy generation is well supported but is constrained by slow diffusion of wind and solar technologies – and a general preference for centralised solutions.

Private car ownership will experience a rapid increase in the first decade of this scenario but more stringent economic and policy incentives manage to slow down this trend. People increasingly use more public transport particularly in cities – and private transport use declines as a result. Advanced biofuel technology and electric cars will reduce oil demand to some extent – but will not be as prominent as they are in scenarios 1 and 2. International aviation and shipping only have moderate growth. Environmental education and awareness will make people much more inclined to 'green' consumption. Behaviour change becomes an important feature and source of carbon reduction after 2020.

Scenario 4: 111GtC 2030

Strong conventional manufacturing industry; economic growth uncertain; strong globalised economy

The Chinese economy in this scenario is a strongly globalised one with a significant contribution from conventional manufacturing industries. GDP growth is more uncertain as it is very export dependent and faces severe constraints from energy and resources availability. The society is less innovative than scenario 2 and pursuit of economic growth leads to strong investment in conventional heavy industrialisation. With incremental innovation and improvement the industry sector is more energy and resource efficient than it is now. Both industry and service sectors have a large share of the economy. Agriculture is less developed because of competition from imports. Carbon emissions keep rising after 2020, albeit at a slower rate than in the pre-2020 period due to structural changes. Emissions peak in 2030 and have to be reduced very quickly to remain within the budget. A social welfare system is established but not very comprehensive due to weak support from private service sectors. A rich and powerful central government provides large scale top-down social welfare care. Technological and science innovations are promoted by government but their diffusion and deployment are slow. China will have a strong industrialised economy and will remain a major player in the global economy by 2020.

Energy and Power mix
Energy demand in this scenario is likely to be the largest of the four scenarios. Similar to scenario 3, this scenario will see a slower roll out of advanced low carbon energy technologies due to a weaker innovative capacity. Renewables will take a long time to mature and deploy, whilst nuclear power takes second place to the continued use of fossil fuels. Oil-based transport fuels remain important, and do not face significant competition until 2030.

Since coal fired power remains dominant in the power sector, the emphasis is initially on more efficient technologies such as ultra-supercritical boilers and IGCC. Expansion of the power capacity and upgrade of existing plants will be the priority before 2015. Fuel switching from coal to gas will take place as more natural gas becomes available from both domestic reserves and international markets. CCS is initially developed slowly but becomes more critical between 2020 and 2030 as it becomes apparent that it needs to be deployed widely to achieve required emissions cuts. Widespread implementation therefore follows from 2030 with a crash programme of new build and retrofitting.

As time progresses, the expansion of fossil fuel use will be moderated by increases in nuclear and large hydro capacity. Renewables other than hydro will develop slower than in scenario 2 due to slower science and technology advances. Many renewables only become competitive and widely deployed after 2030. Decentralised power and heat generation will develop gradually but are constrained by cost and lack of institutional support from a centralised energy system. Solar water heating would be the main form of micro generation by 2010, with significant CHP after 2015. Household PV will only become a competitive choice after 2020.

Industry and services sectors
As a globally-focused economy equipped with strong manufacturing capacity, China will become further integrated into international patterns of production and markets. Chinese industry will maintain a high proportion of heavy, traditional manufacturing – with some shifts up the value chain to more technology intensive industries. Promotion of science and technology innovation has made a significant contribution but has failed to reshape the industrial structure quickly. Energy efficiency and supply chain changes have helped to realise large, incremental emissions reductions, particularly in conventional heavy industries. Overall, heavy manufacturing industries are the largest sub-sector of industry. The service sector will eventually overtake industry in its share of GDP but both will remain very significant.

Household and personal transport
Household consumption and transportation will increase quickly in this scenario due to the large increase in household income and living standards. Offsetting through efficiency improvements is limited compared with the increase in demand. As a result, household and transport will become the largest sources of emissions after 2020. Construction codes for housing place significant emphasis on energy and material efficiency with less attention to integrating renewable energy. As a result, micro generation only manages to provide a small share of household energy consumption. Public transport is well established in most cities but private transport is also highly relied upon by regular commuters. Low carbon vehicle and fuel technologies have made some significant progress globally but high costs prevent them from becoming a popular choice until after 2020. Biofuels and mixed fuel vehicles become more important after 2020. More advanced improvements such as hydrogen powered fuel cells are not widely available in the Chinese market until after 2030. International aviation and shipping demand both increase very fast in response to high demand for mobility and a globalised economy. Environmental education and awareness-raising have managed to encourage some people to choose more green consumptions but it takes time to diffuse into wider community.

Next steps

This working paper has set out progress so far in the development of a set of cumulative carbon emissions scenarios for China. The paper first discussed the key features of some previous scenarios – including scenarios for China and Tyndall Centre scenarios for the UK. The paper then set out the key steps in the development of the new Tyndall Centre China scenarios – including the calculation of cumulative emissions budgets for China and the selection of medium-term emissions pathways from Chinese and international sources. The latter part of the paper has then elaborated the four scenarios that have been chosen, and set out storylines which include trends in economic development, industrial structure and technological change.

These storylines will now be used to inform a more detailed quantitative exploration of each scenario. This will assess the changes that will be required for China to remain within the assigned carbon budget in each case. It is likely that this process will require some iteration – and some revisiting of the assumptions set out for the different scenarios within this working paper. However, further analysis will retain the important distinctions between the scenarios

– particularly the quicker, more radical changes in technology and industrial structure that are included in scenarios 1 and 2, and the later turning points in emissions in scenarios 2 and 4.

Once the quantitative work is complete, the final task of the project will be to consider the implications of the scenarios for action in the short to medium term. This will focus on technology and/or policy options that are being implemented or are being developed for future deployment. In assessing the potential for these options, and the challenges of implementation, the research will consider the implications for Chinese policy and for international energy and climate policies. The final results will be launched in early 2009.

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References

Anderson, K., A. Bows and S. Mander "From long-term targets to cumulative emission pathways: Reframing UK climate policy." Energy Policy **In Press, Corrected Proof**.

Anderson, K. L., S. L. Mander, A. Bows, S. Shackley, P. Agnolucci and P. Ekins "The Tyndall decarbonisation scenarios--Part II: Scenarios for a 60% CO2 reduction in the UK." Energy Policy **In Press, Corrected Proof**.

Böhringer, C. and H. Welsch (2006). "Burden sharing in a greenhouse: egalitarianism and sovereignty reconciled." Applied Economics **38**(9): 981-996.

Bows, A., S. Mander, R. Starkey, M. Bleda and K. Anderson (2006a). Living within a carbon budget. Report commissioned by Friends of the Earth and the Co-operative Bank. Tyndall Centre. Tyndall Centre, Manchester.

Bows, A., S. Mander, R. Starkey, M. Bleda and K. Anderson (2006b). Living within a carbon budget. Manchester, Tyndall Centre for Climate Change Research.

Dai, Y., Y. Zhu, C. Yu, Z. Liu, Y. Kang, Q. Bai and H. Xiong (2004). Scenario Analysis on Energy Demand. China's National Energy Strategy and Policy 2020, Energy Research Institute of National Development Reform Commission.

European Commssion (2007). Limiting global climate change to 2 degrees Celsius - The way ahead for 2020 and beyond. COM 2007 / 002 Final. Brussels, European Commission.

Grubb, M. (1995). "Seeking fair weather: ethics and the international debate on climate change." International Affairs **71**(3): 463-496.

Gupta, S. and P. M. Bhandari (1999). "An effective allocation criterion for CO2 emissions." Energy Policy **27**(12): 727-736.

IEA (2006). World Energy Outlook 2006, International Energy Agency (IEA).

IEA (2007). World Energy Outlook 2007. Paris, International Energy Agency.

Intergovernmental Panel on Climate Change (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the IPCC. Geneva, Switzerland, IPCC.

IPCC, Ed. (2000). Emissions Scenarios. Special Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, UK.

IPCC (2007a). Climate Change 2007: Synthesis Report. Valencia, Spain, The Intergovernmental Panel on Climate Change.

IPCC (2007b). Climate Change 2007: The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the IPCC. Geneva, Switzerland, The Intergovernmental Panel on Climate Change.

Lardy, N. R. (2007). China: Rebalancing Economic Growth. Conference: The China Balance Sheet in 2007 and Beyond. C. F. Bergsten, B. Gill, N. R. Lardy and D. Mitchell. Peterson Institute for International Economics, Washington, DC, Center for Strategic and International Studies / Peterson Institute for International Economics.

Leimbach, M. (2003). "Equity and carbon emissions trading: a model analysis." Energy Policy **31**(10): 1033-1044.

Lin, J., N. Zhou, M. Levine and D. Fridley (2008). "Taking out 1 billion tons of CO2: The magic of China's 11th Five-Year Plan?" Energy Policy **36**(3): 954-970.

Mander, S. L., A. Bows, K. L. Anderson, S. Shackley, P. Agnolucci and P. Ekins "The Tyndall decarbonisation scenarios--Part I: Development of a backcasting methodology with stakeholder participation." Energy Policy **In Press, Corrected Proof**.

Meinshausen, M. (2005). On the Risk of Overshooting 2°C'. Avoiding Dangerous Climate Change, Exeter, 1-3 February 2005, MetOffice.

Meinshausen, M. (2007). Stylized Emission Path. background note for UNDP Human Development Report 2007/08.

Metz, B. (2000). "International equity in climate change policy." Integrated Assessment **1**: 111-126.

Miketa, A. and L. Schrattenholzer (2006). "Equity implications of two burden-sharing rules for stabilizing greenhouse-gas concentrations." Energy Policy **34**(7): 877-891.

Ridgley, M. A. (1996). "Fair sharing of greenhouse gas burdens." Energy Policy **24**(6): 517-529.

Rive, N., A. Torvanger and J. S. Fuglestvedt (2006). "Climate agreements based on responsibility for global warming: Periodic updating, policy choices, and regional costs." Global Environmental Change **16**(2): 182-194.

Rose, A. (1992). Equity considerations or tradable carbon emission entitlements. Combating global warming: study on a global system of tradable carbon emission entitlements, United Nations Conference on Trade and Development, Geneva.

Rose, A. and B. Stevens, Eds. (1993). The efficiency and equity of marketable permits for CO2 emissions. The Economics of Global Warming. Cheltenham, Edward Elgar.

Rose, A., B. Stevens, J. Edmonds and M. Wise (1998). "International equity and differentiation in global warming policy." Environmental and Resource Economics **12**: 25-51.

Wen, J. (2008). Report on the Work of the Government. Report delivered by the Premier of the State Council at the First Session of the Eleventh National People's Congress. Beijing.

Winkler, H., R. Spalding-Fecher and L. Tyani (2002). "Comparing developing countries under potential carbon allocation schemes." Climate Policy **2**(4): 303-318.

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