Climate change mitigation: a defining challenge for China.

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Abstract

Successful mitigation is important for China not only because it will avert dangerous and potentially catastrophic climate change. It is also important, and a defining challenge, because it will only be possible if China is successfully dealing with major economic reform challenges – increasing energy prices, reforming the energy sector, rebalancing its economy – and if it is assuming a greater responsibility for global leadership.

1. Introduction

Reducing greenhouse gas emissions is a defining challenge for China in two senses. First, it is required to avert dangerous and potentially catastrophic climate change. And, second, an effective response to climate change requires fundamental economic reforms and poses critical questions for China's emergence on the international stage as a superpower. Success on the mitigation front will be a good indicator of overall domestic reform progress and of China's peaceful and responsible global rise.

The paper begins in Section 2 with a summary of China's historical and projected emissions trajectory, an assessment of its mitigation target, and an analysis of its objectives in relation to energy and the environment. Section 3 examines the desirability and feasibility of carbon pricing, and Section 4 analyzes the importance of energy sector and broader economic reform. Section 5 considers the very difficult international environment for mitigation and propose some strategies for China. Section 6 concludes.

The analysis is in terms of carbon dioxide from fossil fuels, with a particular focus on the electricity sector. This is partly for tractability, partly because of their growing importance, and partly because CO_2 emissions from fossil fuels are separately targeted by China. Sections 2 to 4 draw on World Bank (2010a), which I recently co-authored with Leo Dobes. This report was written for the APEC economies, and so has an Asia-Pacific focus, which is a natural lens through which to analyze China's efforts and challenges.

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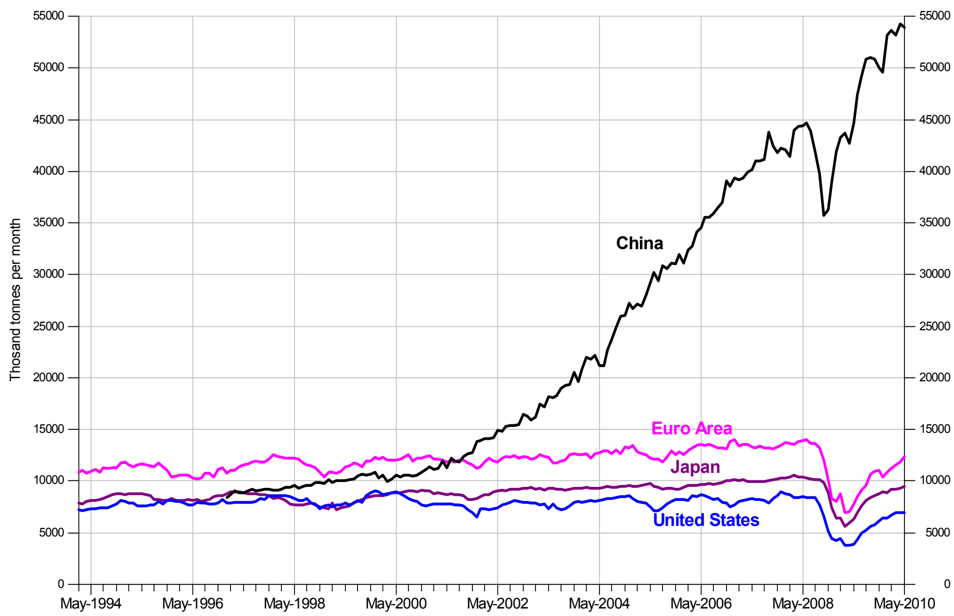
2. China's climate change mitigation challenge and objectives

China's emissions trajectory

China's rise to industrial superpower status – illustrated by comparative steel production volumes in Figure 1 below – has accelerated global emissions growth. China is now the largest emitter of CO_2 (from fossil fuels), with 25% of the global total in 2009, considerably ahead of the second largest annual emitter, the US with 17% (PBL, 2010). China has been responsible for 72% of the world's growth in CO_2 emissions (from fossil fuels) between 2000 and 2009, a period during which China's emissions grew at an annual average rate of 9.4%, and the rest of the world's at 0.8% (PBL, 2010).

Of course, in terms of per capita emissions or accumulated emissions, China's emissions still greatly lag those of the United States. However, one can safely say that there can be no satisfactory global response to climate change without the active participation of China.

Figure 1: China: rise of a steel giant



Production of steel in China, Europe, Japan and the United States, 1994-2010

Notes: Steel production in thousands of tonnes per month, seasonally adjusted.
Source: OECD Main Economic Indicators, World Steel Institute; compiled by Outlook Economics (2010).

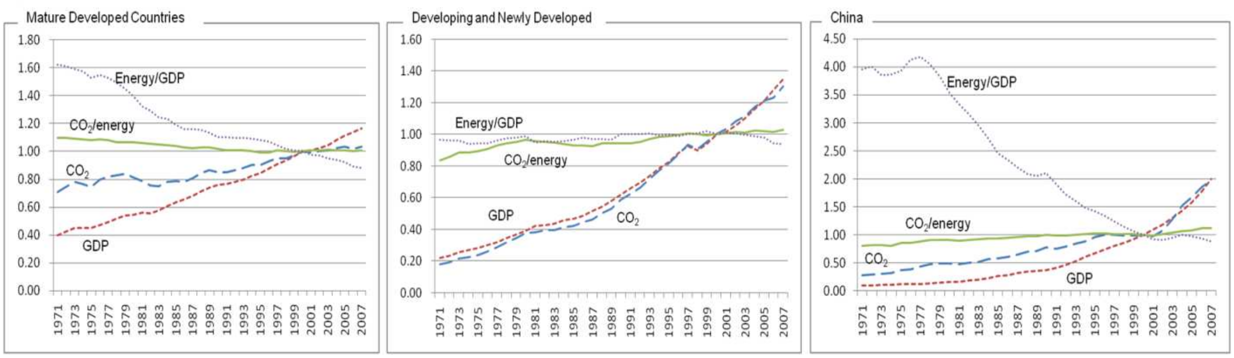
China historical emissions trajectory is unique. Emissions growth in any country is a function of GDP growth, as well as changes in energy intensity (the ratio of energy consumption to GDP) and the carbon intensity of energy. As Figure 2 shows, using the APEC economies to illustrate, in most developing economies, emissions closely track output, whereas in most developed economies emissions lag output. With output growing faster in (successful) developing economies, not surprisingly emissions grow much faster in many developing than developed economies.

The close link between emissions and output in developing economies reflects two features. First, the carbon intensity of energy among developing economies has been on a slight upward trend, reflecting the move away from biomass and increasing dominance of coal-fired generation. Burke (2010) demonstrates that the carbon intensity of energy of a developing economy increases as it develops before it starts to decline. Second, energy intensity is remarkably flat among most developing economies (Sheehan, 2008), that is, energy grows at roughly the same rate as output.

As Figure 2 shows, China's experience is consistent with the generalization that the carbon intensity of energy will increase over time in developing economies. China in fact has the fifth highest carbon intensity of energy of the world's large economies (with populations above 20 million). This unfortunate environmental reality reflects China's relatively strong endowment of coal.

However, China's experience is a clear exception to the otherwise well-supported generalization that the energy intensity of developing economies remains constant over time. China's energy intensity fell over the 1980s and 1990s, as a result of market liberalization, the relative decline of heavy industry and perhaps power shortages, but has flattened out since 2000. As a result, as Figure 2 shows, emissions grew more slowly than GDP pre-2000, but have since roughly tracked GDP.

Figure 2: In most developing economies, but not in China (until recently), CO_2 emissions track GDP



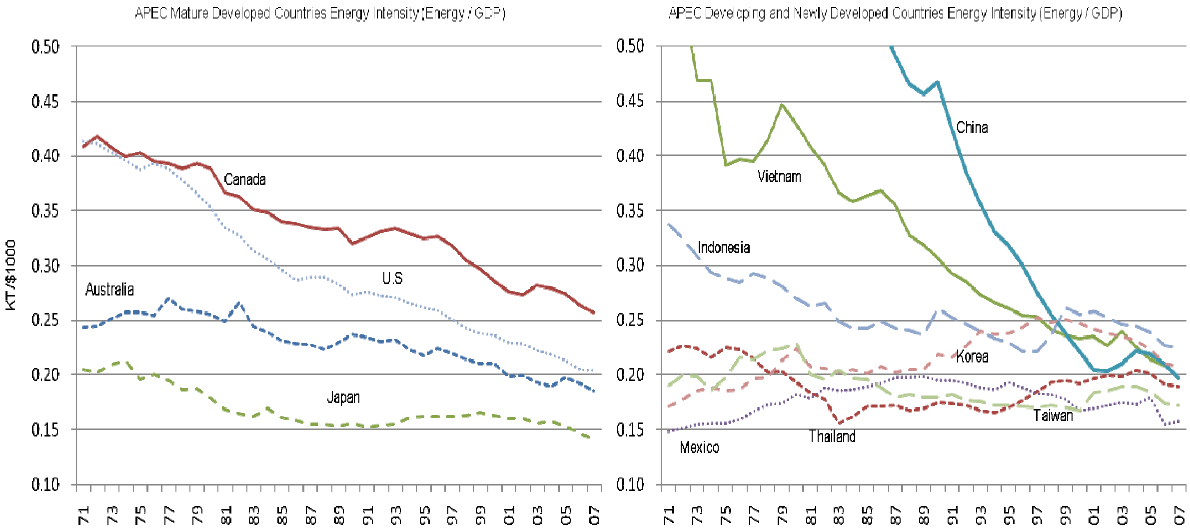
CO_2, GDP, emissions intensity of energy, and energy intensity of GDP for three groups of APEC economies, 1971-2007 (2000=1): (a) mature developed economies, (b) developing and newly developed economies excluding China and Russia, and (iii) China,

Notes: Mature developed economies are Australia, Canada, Japan, NZ and US. Developing and newly developed are all others apart from China and Russia. Data for PNG is missing. GDP is measured in billions of constant year (2000) US$, using purchasing power parities (PPPs) to convert from local currency. Energy is measured in Mtoe (million tonnes of oil equivalent), and CO_2 is measured in millions of tonnes.
Source: IEA (2009a).

Perhaps the biggest policy question relating to mitigation in China is whether the 2000-2005 experience represents a new norm, and how hard it will be to revert to the decline in energy intensity seen in previous decades. It is too early to answer this question definitively, and, as discussed below, recent data is unclear. However, Figure 3 suggests that whereas China entered its reform era with an extraordinarily high energy intensity, it has now become a 'normal' developing country in terms of both the level and trend of its energy intensity.[2] This itself would suggest that, absent deliberate policy action, China's energy use and thus its emissions will continue to track GDP closely.

[2] Though note that more recent PPPs give a lower GDP for China and thus would give it a higher energy intensity.

Figure 3: China's energy intensity used to be extraordinarily high, but now looks average



The ratio of energy consumption to GDP for selected APEC economies, 1971-2007

Notes: See notes to Figure 2.
Source: IEA (2009a).

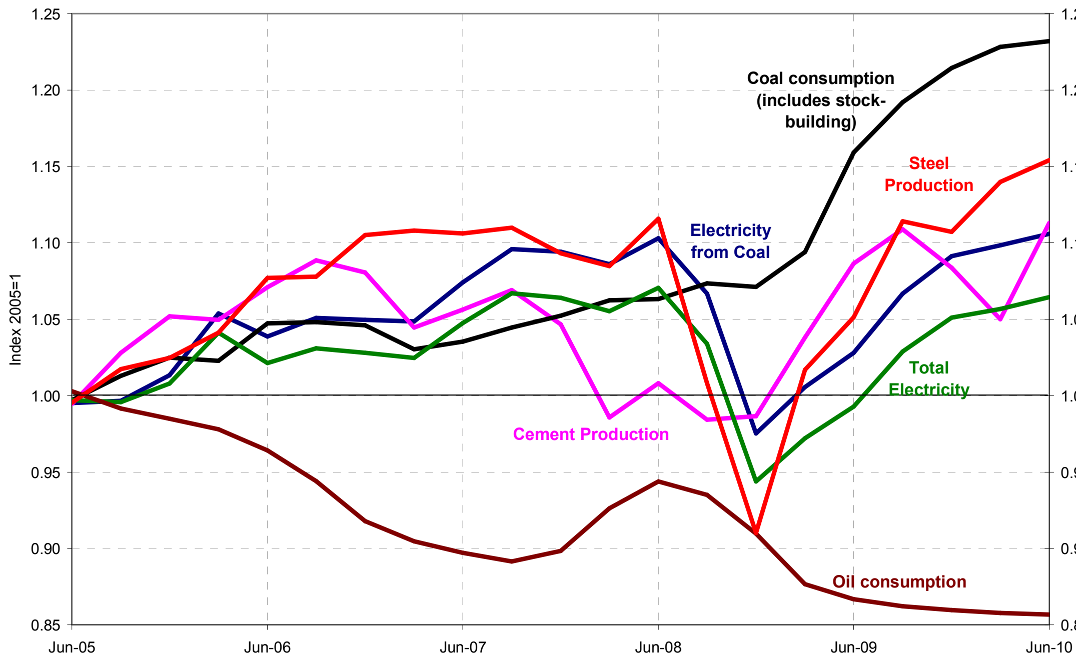
Alarmed by the sharp growth in energy over the Tenth Five Year (2000-2005), China has sought to reduce energy intensity over the Eleventh Five Year Plan, with a target of a 20% reduction between 2005 and 2010. As Wang (2010) and Zhou, Levine and Price (2010) explain, China has pursued this target by cascading it downwards into a series of targets for provinces and large enterprises. Thus each province has been given its own energy intensity reduction target (above, below or equal to 20%). Similarly, each province has translated its goal into targets for its cities and counties. The top 1000 enterprises have also been required to show energy savings, and have each been given their own, tailored targets. Each provincial leader has been required to sign a contract taking responsibility for its energy intensity target with the central government. City and country leaders have likewise been required to sign contracts with their provincial government. Contracts have also been signed with enterprise managers. Progress of both provinces and enterprises is reported annually at the highest political level, and is taken into account during the performance evaluation of provincial, local and enterprise managers. China has also set detailed quantitative targets for closing down old and inefficient plants and factories in major industrial sectors. It has also established ten new projects, to introduce more efficient coal-fired power plants, and to promote energy-efficient lighting and more efficient buildings, and so on. These projects have been backed by high levels of government spending, expected to exceed $10 billion by the central government alone in the current year. A number of fiscal policies have also been used. Energy-intensive industries have been subjected to higher electricity prices and reduced export rebates.

The success which China has had in achieving its objective of a 20% reduction in energy intensity is unclear. Official statistics suggested an initial decline in energy intensity, accelerating as the global financial crisis hit (as energy-intensive exporters were hit hard), but then a reversal during the infrastructure-intensive stimulus period. In May 2010, Chinese authorities announced that energy intensity had increased by 3.2% in the first quarter of 2010 relative to the first quarter of 2009, and also announced an ‘iron hand’ crackdown, with new measures to ensure the 20% target is met. Media reports indicate that factories have been shut down, and in some cases electricity generators stood down in order to achieve the target. Latest announcements indicate a 15.6% reduction in the first four years, and then a further 3% reduction in the first 9 months of this year, which would put the 20% target well within reach by the end of this year.

However, China’s published statistical data suggest a reduction in energy intensity of only 10% up to 2009 (updated from Howes, 2010b). Measurement changes introduced as a result of the 2009 Economic Census make published 2005 and 2009 energy figures non-comparable. A consistent series of energy statistics is yet to be released, nor has any justification for the large revision in energy figures been provided. It is not clear that official announcements should be accepted at face value, and without further scrutiny.

Given the uncertainty around recent trends in energy intensity, an alternative is to to look at proxies for or drivers of energy demand or intensity. Figure 4 shows that most relevant intensities have increased, with only oil intensity declining. Between the first half of 2005 and the first half of 2010, China’s steel production increased by 94%, cement by 86% and electricity by 75% (first quarter comparison), all above the extraordinarily rapid rate of GDP growth of 71% (an annual average growth in GDP of 11.3%). And this in a period which encompassed the global financial crisis. Given these figures, the only way a reduction in energy intensity could have occurred (beyond oil) is by improvement within these sectors, leading to more efficient steel, cement and electricity production. No doubt this has occurred, but whether the improvement in efficiency has been enough to offset these adverse trends is unclear.

Figure 4: Steel, cement, electricity and electricity from coal production, as well as coal consumption, have all risen relative to GDP since 2005



Notes: Series show production series divided by GDP at constant prices and indexed to 2005=1. Series are seasonally adjusted. Coal production and import and export data are updated from the NBS and Chinese customs websites before seasonal adjustment. (June quarter 2010 data is a forecast based on data to May.) Note that coal consumption as derived implicitly includes stock-building which would probably have been positive in the last quarter of 2008 as the global financial crisis hit. Also the NBS coal production source data, used to calculated coal consumption, has probably not been adjusted for changes in the number of coal mines in the economic census between 2005 and 2009.
Source: OECD Main Economic Indicators Database, China NBS web site, ADB database, Chinese Customs, Outlook Economics CHN-TRYM database; compiled by Outlook Economics (2010).

While further analysis is needed, these figures both cast doubt on whether the 20% target has been achieved, and show that whatever improvements China has made with respect to energy efficiency have come not because of but despite the underlying structural trends in the economy

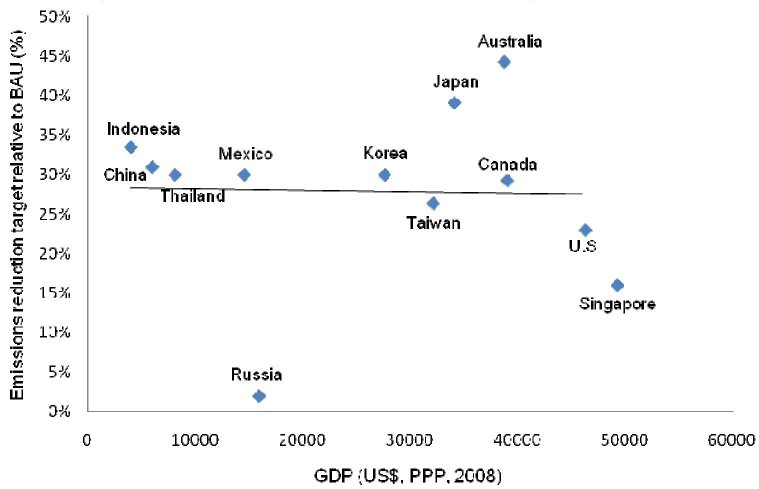
It is also important to put the energy intensity figures in perspective. What matters for environmental outcomes is not improvements in energy or even emissions intensity, but emissions themselves. Even if energy efficiency targets have been met, China's emissions growth continues to be super-charged because of the country's extraordinarily high GDP growth. China's reported 8.4% annual average growth in CO_2 emissions (from fossil fuels) between 2005 and 2009 (PBL, 2010) is well above most 'business as usual' or 'reference case' scenarios for that country. The 2008 World E*conomic Outlook* (IEA, 2008a) has CO_2 emissions in China growing at an annual average of 5.1% between 2006 and 2015 under its reference case. In projections from the World Bank (2010b), annual average emissions growth between 2010 and 2015 is 4.6%. Even Garnaut *et al.* (2009), who assume continued rapid growth in developing economy emissions under business as usual, project 7.1% annual average emissions growth for China between 2005 and 2015. It is remarkable that China is exceeding these projections in a period which encompasses a global downturn.

China's mitigation objectives

In 2009, for the first time, China announced that it would subject itself to an emissions constraint. It would aim to reduce CO_2 emissions intensity in 2020 by 40-45% compared to 2005. China has also adopted a renewable energy target of 15% by 2020 up from 8% in 2006.

The general consensus of analysts is that the Chinese emissions target is an ambitious one which will not be met without considerable policy effort. Figure 5 illustrates this point by comparing national targets relative to (one set of) estimates for 'business as usual' for a range of APEC economies. China's target comes in as at least as ambitious as those of several other much richer economies, including Korea, Canada, and the United States. It would require 30% fewer emissions than China would experience under business as usual. If China's target is achieved, its absolute and per capita emisions would still increase, but by much less than would otherwise be the case. Its per capita emissions at the end of the decade would be 7 rather than 10 tonnes, still up from almost 5 tonnes today, but a savings of about 4 billion tonnes of CO_2 (more than 10% of current annual global emissions of CO_2 from fossil fuels).

Figure 5: China's emissions reduction target is ambitious



2020 APEC emission control targets expressed as a reduction relative to business as usual (BAU)

Notes: National targets as recorded in the Copenhagen Accord or other statements. Where a target range has been committed to, the mid-point of that range is selected.
Source: World Bank (2010a)

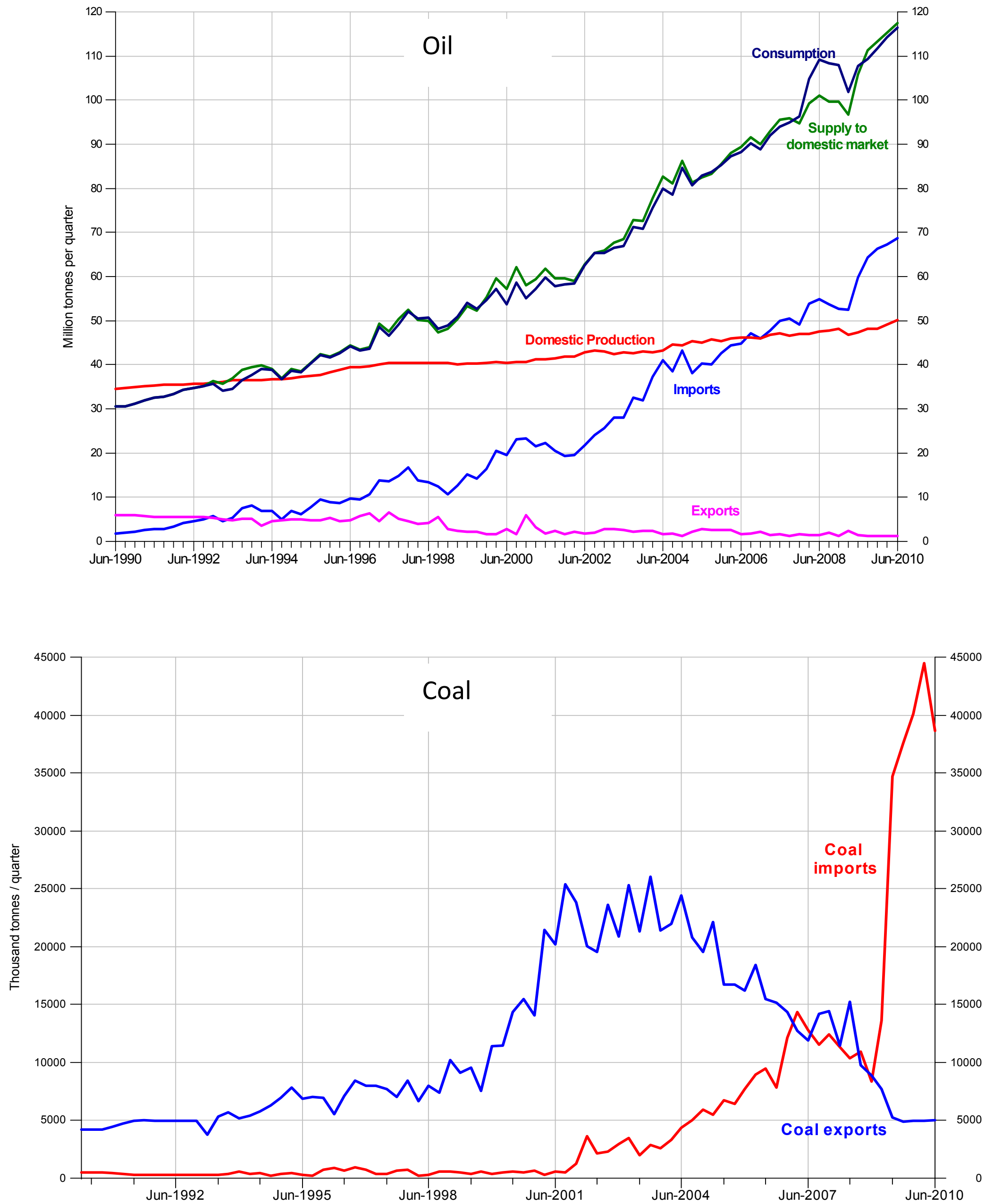
Why has China adopted both an emissions target and a renewable target? There are four objectives in the energy-environment space which are driving action.

First, the risks of unmitigated climate change are clearly a factor, as is China's perceived need to be seen to be contributing to this global problem.

Second, China is seeking to tackle national environmental problems. China has 13 of the world's 20 most polluted cities, 30% of its land is damaged by acid rain as a result of sulphur emitted from coal, and health damages from air pollution are expected to reach 13% of GDP in 2020 (see, for example, Zissis and Bajoria, 2008). Millions face serious indoor as well as outdoor air pollution problems. A meta-analysis of epidemiological studies concluded that “indoor air pollution from solid fuel use in China is responsible for approximately 420,000 premature deaths annually, more than the approximately 300,000 attributed to urban outdoor air pollution in the country.” (Zhang and Smith, 2007, abstract).

Third, energy security is a growing concern. China has long been reliant on oil imports, and has just recently become a significant coal importer (Figure 6). At current production rates, China’s currently proven coal reserves will only last another 41 years (World Bank, 2010a). That said, energy security concerns will continue to revolve around oil more than coal. China already imports almost 60% of its oil needs, but in 2010 will import less than 10% of its coal. Worldwide, there is a lot of coal left. Garnaut (2008, Table 3.3) reports that, at 2007 production rates, the world has 139 years of coal left in its reserve base, as against only 60 years of gas and 40 years of oil. Also, unlike oil, much of that coal is in secure locations, such as Australia.

Figure 6: China, long and increasingly dependent on oil imports, is now also a net coal importer

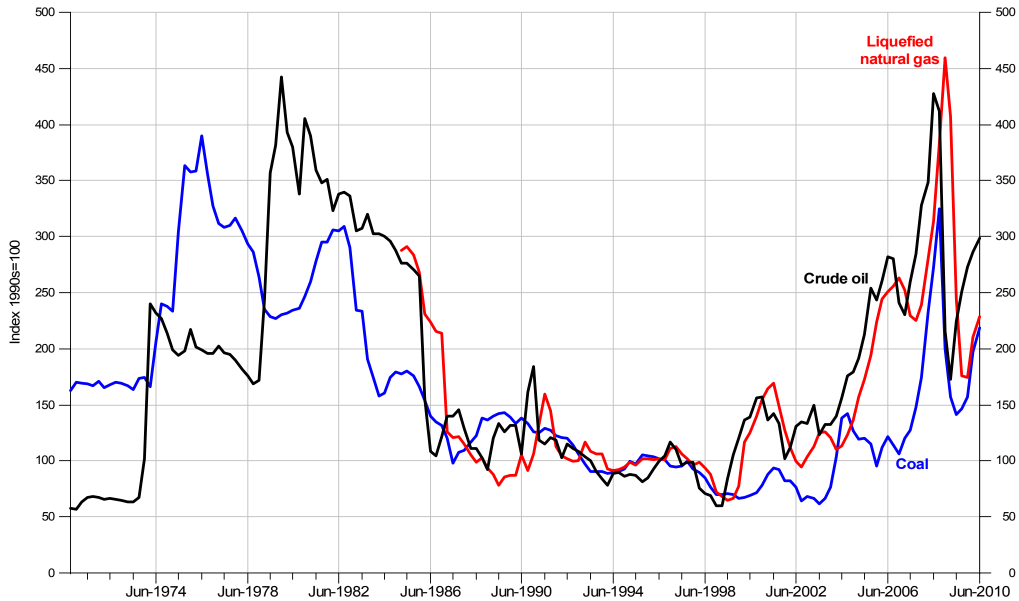


Oil and coal imports and exports, and oil consumption and production, China, 1990-2010.

Notes: Series are seasonally adjusted. Updated trade data taken directly from the customs web site and cross checked against data from the World Trade Atlas. June quarter is a forecast based on data up to May.
Data source: CEIC Database, Chinese National Bureau of Statistics, Chinese customs, OECD Main Economic Indicators Database, World Trade Atlas, Outlook Economics CHN-TRYM database; compiled by Outlook Economics (2010).

The volatility and overall upward trend in world energy prices over the last decade (Figure 7) have also heightened energy security concerns.

Figure 7: World energy prices have been volatile and rising over the last decade



World prices for crude oil, LNG, and coal, adjusted for inflation (1990=1)

Notes: Data is quarterly. Series are converted from US$ to more currency neutral SDRs, divided by the G7 CPI to convert them to constant price terms and then indexed to 1990s levels (average of the decade) for the purpose of comparison. Oil prices are the IMF indicator series (which is an average across a number of types of crude). LNG prices are the price of Russian LNG in Europe. Coal prices are based on Australian thermal coal export prices.

Source: IMF International Financial Statistics, OECD Main Economic Indicators; compiled by Outlook Economics (2010).

Fourth, China is seeking technological advantage. China, like a number of economies around the world, increasingly views clean energy and more broadly low-carbon technology as a future major source of innovation, the 'next big thing.' China seeks to become a leading global supplier and eventually developer of these new technologies. Dechezleprêtre *et al*. (2008) measure technological innovation in respect of climate change mitigation using patent filings. Japan alone is responsible for 37% of the world's climate change mitigation inventions (Table 1). The US is in second position with 11%, and China is in fourth with 8%. China's 2007 Medium and Long-term Development Plan for Renewable Energy explicity identifies the deployment of Chinese intellectual property domestically as a policy objective.

Table 1: Top 12 inventors in climate change mitigation technologies, with average percentage of total global inventions across different mitigation technologies

Country	Rank	Average % of world's inventions
Japan	1	37.1%
USA	2	11.8%
Germany	3	10.9%
China	4	8.1%
South Korea	5	6.4%
Russia	6	2.8%
Australia	7	2.5%
France	8	2.5%
UK	9	2.0%
Canada	10	1.7%
Brazil	11	1.2%
Netherland	12	1.1%
Total	-	87.2%

Notes: Inventions are measured based on patent count data. The percentages shown average over 13 different climate change mitigation technology areas. These include not only renewable energies, but also relevant inventions in the area of building, lighting, CCS and cement.

Source: Dechezleprêtre *et al*. (2008).

All four of these objectives are important for Chinese policy makers. Together, they make up what is now called the 'green growth' agenda, most famously embraced by Korea. There are of course synergies between the four objectives. By pushing down global energy prices, global action on climate change would improve the terms of trade for economies such as China, and thus improve energy security. But there are also trade-offs. An emissions reduction target on its own might undermine energy security goals. Carbon capture and storage (CCS) is an example. CCS will help reduce emissions, but will also worsen local air pollution and weaken energy security, since it will significantly reduce the efficiency of coal plants. Likewise, some measures to improve energy security can increase emissions. Coal-to-liquid conversion (currently under consideration and/or development in several Asia-Pacific economies, including China) will reduce reliance on oil imports, but will increase emissions.

This mix of objectives, and the possibility of trade-offs between them, demands a mix of instruments. This is certainly what we see in China, where a whole raft of instruments from the command and control and regulatory approaches discussed earlier to a range of feed-in tariffs and special tax and tariff concessions (as summarized, for example, in World Bank, 2010a) have been used to date. UNDP (2010, p.82) notes that "There are few, if any, developing economies that have promulgated as many laws, policies and other measures to support low carbon development as China." This is probably true not only in relation to developing economies. What we have not seen so far in China is the introduction of a carbon price. However, there are are several media reports suggesting that the introduction of a carbon price is now on the agenda. Some media reports suggest that China is contemplating the introduction of a carbon tax. Rates mentioned are 20 Yuan per tonne of CO_2 (about $3) rising to 50 Yuan by 2020.[3] Other media reports suggest that China will in fact introduce emissions trading. The next section considers the desirability and feasibility of the introduction of carbon pricing into China.

3. Carbon pricing: desirability and feasibility

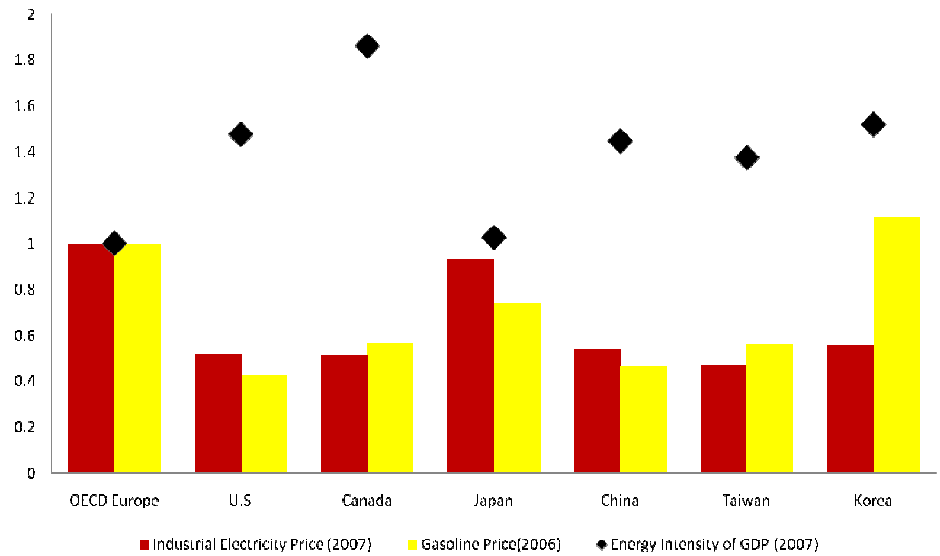
For most economists, the introduction of carbon pricing is a litmus test for the seriousness of governments in mitigating climate change. For example, Nordhaus (2008, p.22) writes: "Whether someone is serious about tackling the global-warming problem can be readily gauged by listening to what he or she says about the carbon price." In Nordhaus' view "To a first approximation, raising the price of carbon is a necessary and sufficient step for tackling global warming." (*ibid*) This section considers whether carbon pricing be desirable for China, and whether it would be feasible.

Carbon pricing would not suffice as a policy response to climate change for China (or other developing economies). Complementary policies would be needed in three areas. First, so-called technology policies, such as R&D subsidies and feed-in tariffs, would be needed to promote technological leadership. Views on the wisdom both of an activist industrial policy such as this are mixed, and of individual policies to achieve it are mixed, but, taken the objective as given, a more targeted approach to technological innovation and dissemination is needed than provided by carbon pricing. Second, there is a risk that carbon pricing on its own would lead to substitution from emissions-intensive coal to less-emissions-intensive oil, thus reducing emissions but worsening energy security. This would need to be addressed by complementary policies to tax oil, or again promote renewables, so that the substitution is not from coal to oil but away from fossil fuels altogether. (Gas is already being promoted but is supply-constrained.) Third, there are still several hundred million households reliant on biomass for cooking and heating in China, with serious negative health consequences. A carbon price, as a tax on modern energy, could conceivably make it harder for these households to escape the traditional energy sector. However, the empirical evidence (summarized in Wadhwa *et al.*, 2003) suggests that in fact exit from traditional energy is not price sensitive, and that what is more important are complimentary policies either to reduce the health effects of using traditional energy sources, or to extend access to the modern sector.

Although not sufficient on its own, carbon pricing would seem to be an essential part of an effective policy response to the mitigation challenge. There is no doubt that if China wants to achieve an ambitious emissions objective, such as the one that it has just adopted, it will have to increase the price of energy. Figure 8 summarizes the challenge facing China. It compares China (and Taiwan and Korea) to two sets of developed economies: the US and Canada on the one hand, and the EU and Japan on the other. The US and Canada have cheap energy (low electricity and petroluem prices) and a high energy/GDP ratio. The EU and Japan have expensive energy and a low energy/GDP ratio. China currently looks much more similar to the US and Canada than it does Europe and Japan, with relatively low energy prices and relatively high energy intensity. China's mitigation objective on the other hand requires that it ends up looking more like the Europe and Japan than the US and Canada when comparing energy use to GDP. But this must mean much higher energy prices.

[3] http://www.businessgreen.com/business-green/news/2262857/reports-china-impose-carbon-tax

Figure 8: China's future: low energy prices or high energy efficiency?



Electricity prices, gasoline prices, and energy intensity (ratio of energy use to GDP) for US, Canada and Japan relative to the OECD member economies of Europe.

Notes: Energy prices measured in current USD, using market exchange rates; energy intensities measured using PPPs. For energy intensity definitions, see Figure 2. Energy efficiency is defined as the inverse of energy intensity. All OECD Europe values are normalized to one.

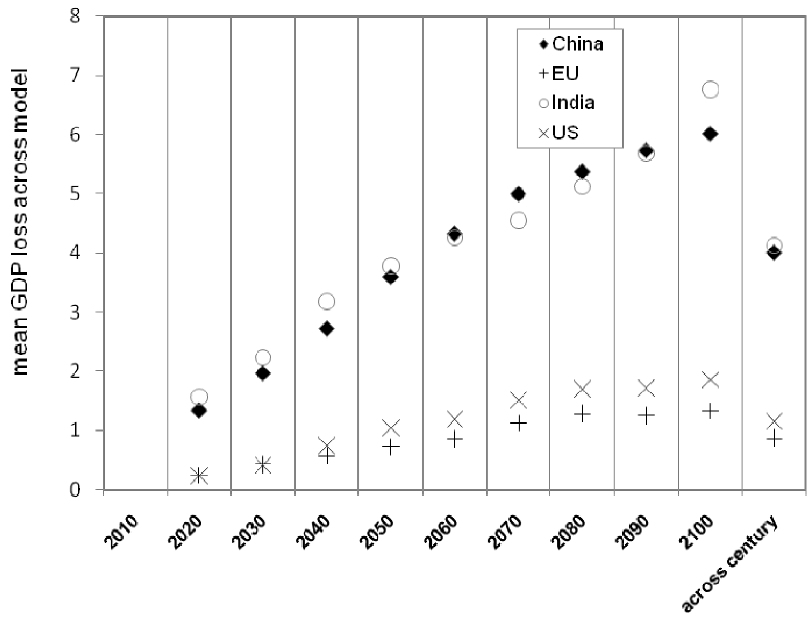
Sources: IEA (2009a, 2010).

Higher energy prices not only would help China reduce emissions, but would have a number of side-benefits as well. First, energy taxes could be a substantial source of revenue. A $20 carbon price applied across fossil fuels could fetch China in excess of 2.5% of GDP by 2020. In general, analysis of the OECD finds that increasing broad-based commodity taxation and reducing personal and corporate taxes are efficiency-enhancing (Johansson *et al.*, 2008, and Arnold, 2008).

Second, energy taxes would be a progressive source of revenue in China. This is very different to the situation in developed countries, where energy is an inferior good (that is, the share of energy in the consumption bundle declines in proportional terms with income). In developing economies, typically the share of (modern) energy in the consumption bundle increases with income (Bacon *et al.*, 2010). Thus, whereas in developed economies, an energy tax is regressive, in developing economies it is progressive (World Bank, 2010a). Thus in developing countries, the introduction or increase in energy taxes does not imply an equity-efficiency trade-off.

These benefits are important because mitigation, even if efficient, will not be cheap in China, at least not without revenue recycling. As Figure 9 shows, most model estimates show mitigation costs as a percentage of GDP to be much higher in developing countries than developed ones (for a single carbon price). Even though some developing countries, including China, will benefit from the positive terms of trade impacts of higher domestic energy prices, the fact that they have much higher emissions intensity to begin with drives up their costs of emission reduction (see Lee, 2010, Howes, 2009b and Stern and Lambie, 2009). However, such costings ignore the revenue impacts of carbon pricing (since they assume the lump=sum recycling of revenues) and also ignore distributional benefits.

Figure 9 Most models show that carbon pricing will be relatively expensive for China.



Cost of a global carbon price for different economies according to a number of different economic models.

Notes: The models are those used in the EMF-22 modeling exercise to estimate the cost to GDP of a global carbon price set at a price high enough, with universal participation, to stabilize the concentration of greenhouse gases at different target levels All models are shown for which cost to GDP results are available (about ten). No international transfers are assumed.
Source: Lee (2010) and EMF (2009).

Overall, introduction of a carbon price, as part of a broader policy mix, would be desirable given China's mitigation and related policy objectives. But would it be feasible? This is a question which is yet to receive the attention it deserves.

Feasibility has two dimensions, one that could be considered broadly political (influencing the likelihood of introduction and level of any carbon price) and one broadly economic (influencing the impact of any carbon price once introduced). Increasing energy prices is politically difficult anywhere, but especially in a developing economy such as China. The fact that, as discussed earlier, modern energy is a luxury good in developing economies might improve the welfare consequences of energy price increases, but it might also raise the political costs, since it means that any energy price increase will disproportionately hit the rich who are also likely to be the politically powerful. Moreover, developing economies such as China have a limited availability of compensation instruments, which again makes the politics more difficult.

The other political barrier to carbon pricing is international rather than domestic. The tardiness of developed economies outside of the European Union to introduce carbon pricing will inevitably bound the ambition of developing economies. If carbon prices are introduced, they will be at a low level: current proposals in Indonesia and China suggest a $5-10 range. Clearly, the lower the price, the lower the impact. Europe's carbon price under its ETS has been volatile. At the time of writing, prices are about 14 Euro (about $20). Prices are expected to rise in the coming years, but neither historical nor projected prices have been sufficient to deter Germany from engaging in a "rush to coal:" Germany currently has some 20-29 GW of coal and lignite generation plants under planning or construction (about 30-40% of current peak demand), and only 3-6 GW of gas (Pahle, 2010). Pahle shows that, at current fuel prices, a carbon price of 40 Euro is needed to favor gas over coal, and argues that investors either don't believe that carbon prices will reach this level, or are worried that gas prices will continue to rise relative to coal, and so require an even higher carbon price.

That said, it is important to take a long-term perspective. Given the science, climate change is unlikely to go away as an issue. Over time, as climate change becomes more evident, more developed economies will introduce carbon prices, and this political constraint to carbon pricing for developing economies will weaken.

Whatever the level at which it is set, would it have an impact? We now turn to this question of the economic feasibility of carbon pricing. Clearly, a carbon price on coal would send a strong signal to commercial consumers of coal, such as steel manufacturers. But much of the energy sector in China is regulated, and here matters are more complex. For concreteness, we focus below mainly on the impact of a carbon price in the electricity sector.

A carbon price will, in an otherwise well-functioning market, push up the relative price of emissions intensive goods, and thereby reduce emissions in four ways. First, it will push consumer demand in the direction of goods which are less emissions intensive (e.g. to wear extra clothing and turn down the heating). Second, it will induce suppliers to make their goods less emissions intensive (e.g. to make electricity with gas instead of coal). Third, it will lead investors to invest in less emissions-intensive projects (e.g. to build an aluminum smelter which runs on hydro rather than thermal power).[4] And, fourth, carbon-pricing would give a financial incentive for innovators to develop new products which are less emissions-intensive (e.g. to invent a hydrogen or electric car).

The effectiveness of the fourth channel of induced innovation will depend on the extent to which the other three channels are effective. In the case of the electricity sector in China, as I show below, each of the first three channels might in fact be blocked.

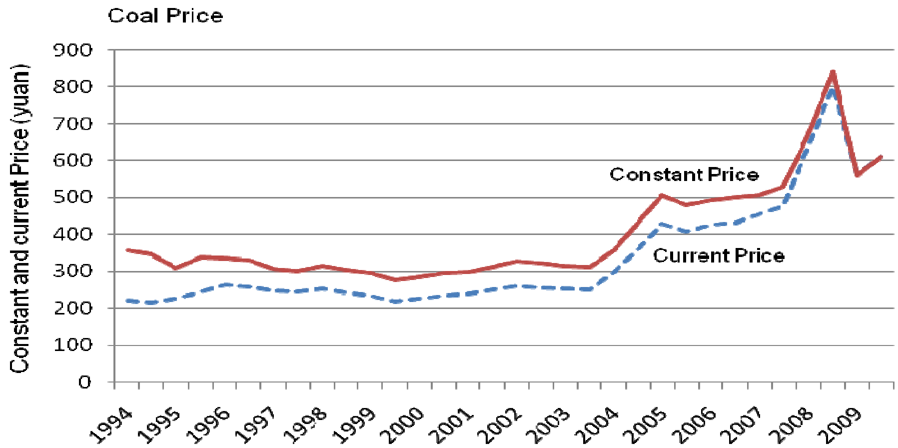
Impact of carbon pricing on demand

For a carbon price to have an impact on demand, it clearly needs to be passed on to final consumers. Coal is the dominanct fuel for electricity in China. In recent years, the price of coal in China has risen sharply, as illustrated by Figure 10, which plots the spot or market price for coal.[5] A lot of coal (about 70%) is sold under long-term contract, but in 2007 price controls for long-term contracts were removed (Rosen and Houser, 2007 p.25). Contract prices are significantly lower than market prices, but should over time follow the latter upwards. Market coal prices spiked in the middle of 2008, with some prices reaching in excess of 1000 Yuan per tonne. At this point, the Chinese government capped the market price at 800 Yuan.

[4] In a world of partial mitigation, suppliers and investors may also respond by moving emissions-intensive production off-shore. This is the problem of carbon leakage.

[5] Mao *et al.* (2008) conclude that the price of coal would be 15% higher if all government subsidies in its production and distribution were removed.

Figure 10: The era of cheap coal in China is over



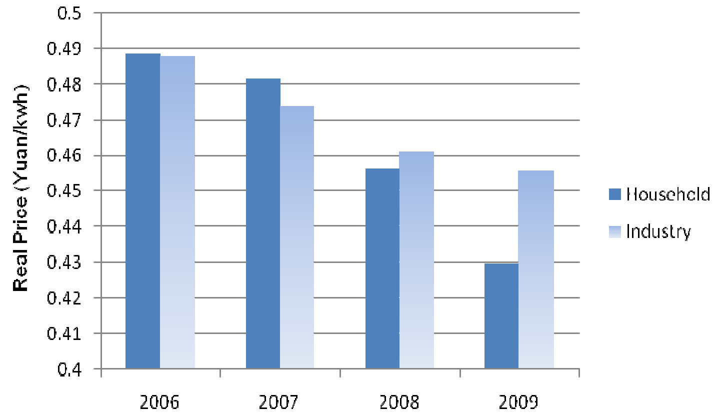
Current and constant spot market prices of coal, 1994 to 2010.

Notes: Six-month average FOB prices per tonne (1000 kg) of coal at the Qinghaungdo Port for 3 types of coal (where available): Datong Premium Mix 6k, Shanxi Premium Mix 5.5k, and Shanxi and Datong Mix 5k. The CPI deflator is used to obtain the constant price series, using 2009 as the base.
Source: National Bureau of Statistics of China (2010) and national Chinese coal data.

Through a series of electricity tariff increases, China greatly reduced electricity subsidies over the 1990s. However, China has found it difficult to pass on the increase in coal costs it has recently experienced. China has a formula in place for adjusting the electricity price every six months if the coal price changes by more than 5%. However, since the end of 2004, when the formula was introduced, although this condition has been met 10 out of 12 times (in relation to coal market prices), the price of electricity has only been changed thrice, and by much less than the formula mandated. In nominal terms, coal prices rose 40% between the first six half of 2006 and 2010, but electricity prices only by about 15%. In fact, over the last few years, electricity selling prices have not even kept pace with inflation, as Figure 11 shows.

The result has been a squeeze on margins in the electricity sector, as seen in Figure 12. In 2003, coal costs were less than half of the price at which grid companies purchased power from generators. In 2008, they were over 100%, and, despite some relief from falling coal prices, at the end of 2009 coal costs still consumed over 70% of coal-fired generator revenue. How is the sector managing to survive? Much coal is still sold under contract, and contract prices would lag spot prices, given the doubling of the latter since mid-last-decade. Generator profits are also being squeezed and the margin between the final selling price and the wholesale power purchase (generation) price has also fallen. Morse, Raid and He (2009) report that Chinese power companies lost an estimated 70 billion Yuan in 2008.

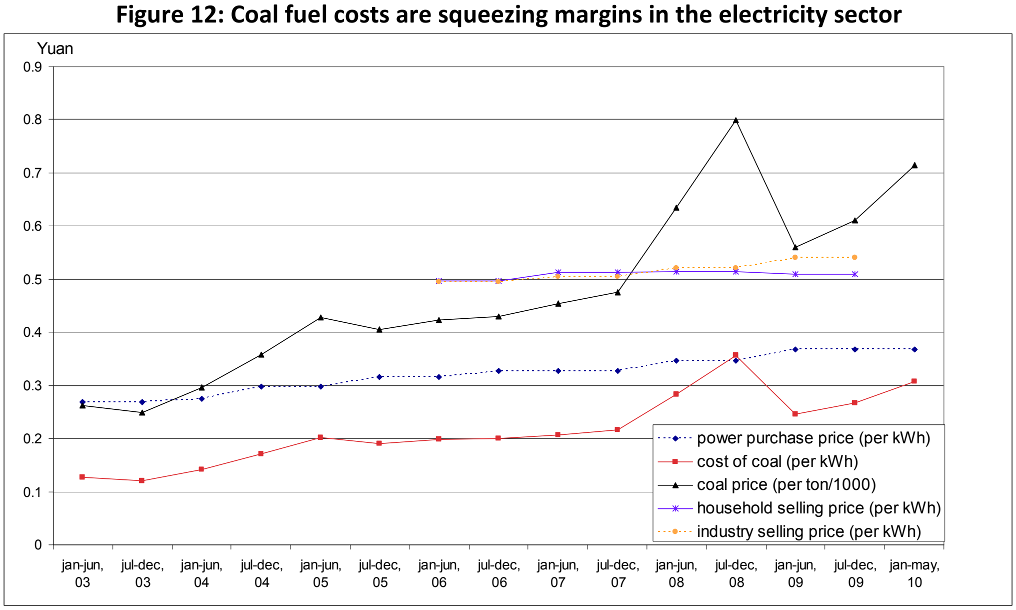
Figure 11: Despite rapidly rising coal prices, electricity prices for industry and household in China have not kept pace with inflation in recent years



Average electricity selling price for industry and households, all of China, 2006-2010

Notes and sources: National prices are calculated by taking weighted averages for provinces from SERC (2006-2009) using total consumption in the province as the weight. Data for Tibet is missing. Average prices (revenue per kWh) are calculated in this way for all consumers and for households. The industry price is then calculated as the average for all categories other than households and agriculture (assumed to pay household prices) using 2007 national electricity consumption data by sector from National Bureau of Statistics of China (2010) for 2007.

Figure 12: Coal fuel costs are squeezing margins in the electricity sector

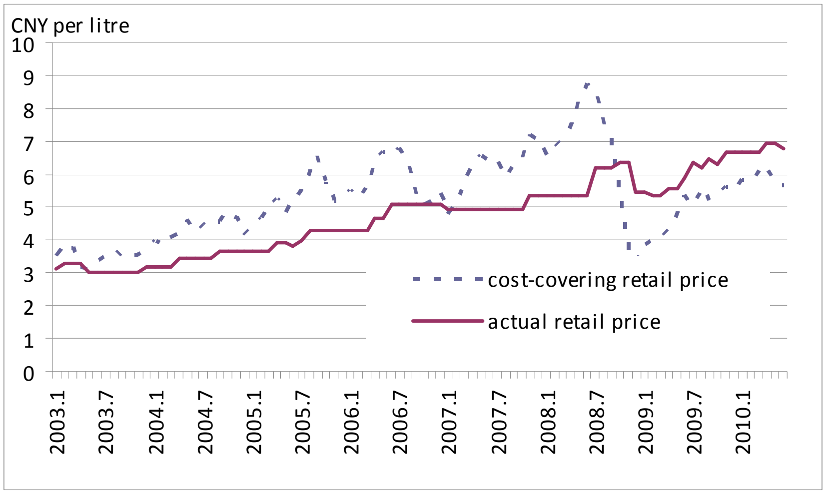


Average coal price (yuan/ton divided by 1000), estimated coal fuel cost, average generation price, and electricity selling price for industry and households (all Yuan/kWh), all of China, 2006-2010

Notes and sources: Current prices used. For household and industry prices see Figure 11. For coal prices, see Figure 10. For assumptions on coal efficiency, see Zhao (2008) and China Electricity Council (2010b). Values for 2008 and 2009 are interpolated. For the (wholesale or generation) power purchase price, information is used from SERC (2006-2009) and public information on tariff increases, averaged across provinces.

Similar problems with cost pass through have ocurred in the petroleum sector, as Figure 13 illustrates. China announced it was moving to market-based pricing for petrol in December 2008, but in May 2009 the government announced that it would set prices to protect consumers when world oil prices exceed $80 a barrel (Kojima, 2009, p.4).

Figure 13: Petrol prices in China follow world prices except when world prices are very high



Actual retail prices for petrol in China, and what they would need to be to cover costs given world prices for crude.

Note: Cost-covering retail prices are based on the world price for crude and include margins for refining and distribution. In January 2009, China increased the fuel tax from 0.2 CNY/liter to 1 CNY. The cost-covering retail price does not include taxes. The price is for Beijing, and for 93-octane gasoline.

Source: Li (2009), updated.

Impact of carbon pricing on dispatch

In the electricity sector, the second channel by which a carbon price would reduce emissions is by changing the fuel mix, or the dispatch order. Here again, pre-existing distortions or constraints might limit the impact of carbon pricing. While China has not yet introduced a carbon price, it has tried to introduce a reform to its electricity dispatch system which mimics a carbon price.[6] Under the Energy Saving and Emissions Reduction in Power Generation or ESERD pilot introduced into 5 provinces, provinces have been instructed to dispatch generators, not on an across-the-board basis as in the past, but rather according to a mix of economic and environmental criteria. To simplify, the dispatch order is: renewable, nuclear, gas, and then coal, with coal plants ordered by their thermal efficiency, from highest to lowest. Note that this is roughly the order that one would expect with a high-enough carbon price, and, indeed, simulations show implementing ESERD would cut emissions by 10%. However, the pilot provinces have only been able to partially implement this pilot, because of the negative financial implications full implementation would have for less-efficient coal-fired units. These units are still valuable as reserve capacity, but, under the Chinese on-grid tariff system, plants only receive a payment if they are dispatched, and so have no incentive to provide stand-by capacity. Instead, if not regularly dispatched, they would simply shut down, thereby depriving the system of valuable spare capacity, in

[6] This paragraph draws on Mercados (2010).

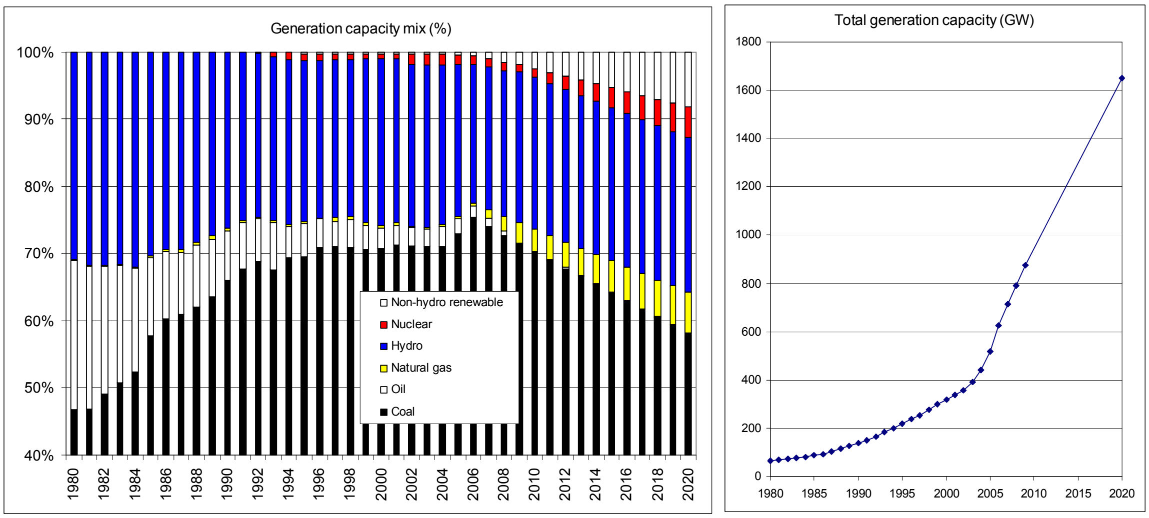
case of an emergency or a spike in demand. Or, put differently, the policy-induced lack of flexibility in dispatch has undermined the impact of the introduction of a carbon price (or, in this case, equivalent).

Impact of carbon pricing on investment

The potential for carbon pricing to influence investment decisions in the electricity sector in China is limited by the continued prevalence of central planning. As Wu, Wen and Duan (2004, p.4) write: "Although the generation sector has already been separated from the utilities in China, investment and construction of new power plants are still under strict control of the government." Private-investment is allowed, but under expansion plans laid down by the central and provincial governments. Zhang and Heller (2004, p.35) note: "Although Beijing no longer aims to control how many restaurants will emerge in the next five years, it does see a need to continue to plan and decide how many power plants to build, where to site them, what fuel they should tap and what prices they will charge. As a result, instead of partially withdrawing from business, the government merely switched its role from directly controlling the power industry via repatriation of all revenues and direction by ministerial fiat to indirectly controlling utility SOEs' access to financial markets and project approval. SOEs in the power sector are not substantially more independent than they were before the reform in terms of power project development."

Price signals are crucial for getting decentralized agents to adjust their actions to meet national targets. But central planners can directly incorporate national targets into their decision making, without any price signal at all. The Chinese government already has capacity targets for all major generation types. Figures that are both official and up-to-date are hard to come by, though will form part of the soon-to-be-released Twelvth Five Year Plan. Figure 14 presents estimates of what China's 2020 expansion targets are or will be, both for total generation capacity, and for different fuel types. They imply not only a rapid aggregate expansion, but significant continued diversification away from coal to gas, nuclear and wind.

Figure 14: China's 2020 generation targets aim to reduce the dominance of coal-fired generation, while doubling total capacity.



Electricity generation capacity by fuel type (%) in China, historical (1980-2009) and projected (2020)

Notes and sources: Target year is 2020; last year of historical data is 2009; for intermediate years, linear interpolation used. Historical capacity data comes from EIA (2010). However, this source doesn't distinguish between coal, oil and gas capacity. The subdivision of thermal capacity into these three types is done using electricity generation data from IEA (2009b), up to 2006 and own sources for 2009 (2007 and 2008 are interpolated). Note vertical axis truncated from below at 40% to magnify the changes envisaged. At the time of writing, there was no public, up-to-date and comprehensive generation expansion plan. Targets were therefore compiled from various public sources. (The 12th Five Year Plan, due shortly, is expected to contain an updated generation expansion plan.)

China is already clearly trying to boost the share of gas, renewable and nuclear energy, and reduce the share of coal. Would planners move further away from coal if they were told to use a carbon price? A precise answer to this would depend on the calculation of the implicit carbon price which would give the outcome shown in Figure 14. However, since China's expansion plans already embody a move away from coal, there can certainly be no presumption that the introduction of a carbon price would influence the generation mix, unless the carbon price was itself very high.

4. Beyond carbon pricing: energy sector and broader economic reforms

Energy sector reforms

The discussion of the previous section should make it clear that, while carbon pricing might be desirable for China if feasible, it may not be feasible in the electricity sector, and perhaps also in the petroleum sector, in the sense that pre-existing institutional conditions would limit or nullify its impact. In the unregulated segments of the fossil fuel market, a carbon price would be expected to influence behaviour, but not, we have seen, in the regulated segments.

This finding points to the importance of energy sector reform to heighten the impact of carbon pricing. This is not necessarily a call for a move away from central planning. Central planning may or may not be efficient, but, as we have seen, it can provide a framework within which environmental considerations can be weighted, even without carbon pricing.

The most important energy sector reform from an environmental perspective would in fact be the strengthening of mechanisms to allow for cost pass through. This is not only critical to influence patterns of demand. If costs are not passed through, then it is also possible that investment plans which promote more expensive but less polluting generation sources will not be implemented due to financial constraints.

Strengthening cost pass through can in theory be done in either of two ways: either by liberalization, or by the use of formulae or established procedures which aim to mimic the behaviour of liberalized markets. In practice, these are far from perfect substitutes, since as long as the government retains control of whatever approach is agreed on, it can continue to exercise discretion. China's own experience testifies to this. As noted earlier, China introduced a formula in 2005 to allow for automatic coal cost pass through in electricity prices, but it has not implemented the required formula. Full liberalization would be possible with respect to petroleum prices, and in relation to generation pricing. Transmission and distribution costs will always need to be regulated, but China could promote cost pass through by establishing independent regulation.

The conclusion that energy sector reform is needed for an effective mitigation response is correct, but potentially misleading unless qualified in two important ways. For concreteness, I again focus on the power sector.

First, it is important to recognize that power sector reforms in developing economies are difficult, and often make slow progress. While there are some success stories, a World Bank (Besant-Jones, 2006) review of power sector reforms concludes that overall "political forces are difficult to align for reform" (p.14), that interest groups "constitute a major impediment to reform" (p.16), and that "successful reform requires sustained political commitment." (p.2) Not surprisingly therefore, "Power market reforms in developing economies are generally tentative and incomplete, and are still works in progress." (p.4). Power sector privatization is particularly challenging. "Most privatization-focused power sector reforms in developing economies have stalled, and some have been abandoned in all but name" (Rosenzweig, Voll and Pabon-Agulado, 2004, p.16).

China is no exception to this generalization. It has made slow progress with electricity reform. In 2002, China split its single, vertically integrated utility into two grid companies (a large one covering most of the country, and a small one in the south) and a number of generation companies (including five large ones). It experimented with wholesale electricity markets in 2002, but that was short-lived and generators no longer bid for dispatch, but sell at centrally-fixed prices. China also established in 2002 a State Electricity Regulatory Commission, but it focuses on technical rather than economic regulation. Prices are still set by government (though the SERC can offer its advice) and, as noted earlier, mechanisms for cost pass-through have been established but are not used. Central planning is still used to guide generation expansion. The IEA's conclusion that "China is caught between the old planning mechanisms and a new approach" (2006, p.16) is probably as relevant today as when it was written.

Second, partial reforms might actually make it more difficult to introduce mitigation measures. The difficulty of introducing a merit-based dispatch system in China, discussed above, is a good example of this. If electricity in China was provided today by vertically integrated utilities, it would easy to introduce merit-based dispatch. It would also be easy if generation and transmission (strictly, power-purchase) were split, and generators were compensated using a two part tariff, separating capacity from actual generation. But what actually happened was that generation and transmission were split, but a two-part tariff was not introduced. It was this partial reform which has made it difficult to introduce merit-based dispatch.

Of course, there are many reasons to undertake energy sector reforms. The main driver is economic. From a climate change perspective, the main reason for introducing energy or power reforms would be to increase the impact of carbon pricing. This is a good reason, but it is important to recognize that if power sector reforms are difficult, then partial reforms are likely, and if partial reforms may have an ambiguous effect, then one cannot be confident that a power sector reform program will in fact help rather than hinder mitigation, at least in the short term

Broader economic reforms

It is not cheap energy that is driving China's massive expansion of energy-intensive goods, such as steel (Figure 1). Energy prices are low in China compared to Europe and Japan but not compared to the US (Figure 8). The search for what Rosen and Houser call "the root causes of [China's] structural over-allocation into energy-intensive industry" (p. 37) must extend beyond the energy sector. As they argue: "the pervasive revealed comparative advantage of heavy industry manufactured goods from China is generally rooted in distortions other than energy inputs." (p. 38).

China is characterized by an exceptionally high investment rate. Huang (2010) explains this by his characterization of China as a country which has liberalized its product markets but not its factor markets. Limited liberalization of the labour, land, financial and energy sector markets have repressed wages, land prices, interest rates and energy prices. Low interest rates and land and energy prices encourage capital-intensive production. Low wages should push in the other direction, but Huang argues that the lack of social security increases savings which further pushes down the cost of capital.

The resulting capital-intensive growth is also energy intensive. Though further quantification is needed, if this analysis is correct, then rebalancing the economy – to reduce investment and increase consumption – should not only be good for short-term economic welfare, but should also reduce emissions. He and Kuijs (2007) argue that a rebalanced Chinese economy would not necessarily grow more slowly (since it would use capital more efficiently), but would use less energy due to more rapid growth of services and less of industry.

It is this link between mitigation and rebalancing which, more than any other domestic issue, makes climate change a defining challenge for China. The international challenges China faces on climate change, to which we now turn, are no less daunting.

5. International dimensions

Recent developments

In 2009, I wrote an chapter in the annual ANU China Update (Howes, 2009a) answering in the affirmative the question of whether China could save the Copenhagen negotiations, and deliver a global deal. While some accuse the Chinese of wrecking the negotiations, in fact Copenhagen, with Chinese support, delivered all three of the ingredients I argued would be critical for obtaining a global deal.

First, in the run-up to Copenhagen, the Chinese government announced its domestic emissions target, the 40-45% target discussed above. Other developing economies followed suit, and by the end of Copenhagen countries responsible for 80% of the world's emissions had announced economy-wide emissions targets.

Second, the developed countries – who already had emissions targets in place or announced – responded with a financing package, promising "USD 30 billion for the period 2010-2012 with balanced allocation between adaptation and mitigation" and a "goal of mobilizing jointly USD 100 billion dollars a year by 2020 to address the needs of developing countries … from a wide variety of sources, public and private, bilateral and multilateral" (UNFCCC, 2010).

And, third, a compromise was reached on the issue of verification or transparency. Developing countries ('Non-Annex I Parties' in UNFCCC parlance) would not be subject to the same requirements as developed countries, but would not get off scot-free either. Rather: "Mitigation actions taken by Non-Annex I Parties will be subject to their domestic measurement, reporting and verification the result of which will be reported through their national communications every two years. Non-Annex I Parties will communicate information on the implementation of their actions through National Communications, with provisions for international consultations and analysis under clearly defined guidelines that will ensure that national sovereignty is respected." (UNFCCC, 2010)

Why, with these critical components in place, was Copenhagen nevertheless a failure? It was not because it didn't deliver a legal text. No one expected it to deliver more than a political agreement. The reason is that the political agreement which Copenhagen delivered, the Copenhagen Accord, contained no reference as to how and by when it would be converted into a legal text. Not surprisingly, this has meant that the Accord has provided little impetus to negotiators as they try to move forward towards an agreement. International negotiations are once again bogged down.

To understand what has gone wrong, we need to go one step further: why was there no agreement on how to convert the Copenhagen agreement into a legal document? The answer to that is there was a fourth issue which most analysts, including myself, failed to give due weight, which defied attempts at reconciliation, namely the issue of legal form. Essentially, China and other developing countries want developed countries to sign up to a second (post-2012) commitment period for the Kyoto Protocol. They might be willing to negotiate a second agreement covering their own commitments, but only if there is a guarantee of a second Kyoto commitment period. Their view is that Kyoto is the main achievement to date of all the international climate change negotiations (stretching back to the early 1990s) and that the developed countries shouldn't be able to walk away from it. The US, on the other hand, which has never ratified Kyoto will have nothing to do with a second commitment period. Other developed countries are less implacably opposed, if a Kyoto is part of a broader deal, but given how hard it was to was to get the Kyoto Protocol ratified (it took 8 years from signing to international ratification), this push for a second commitment period seems like mission impossible. Recall that, although it failed to ratify it, the US at least signed on to the original Kyoto Protocol, which it certainly wouldn't for a second commitment period.

There is no obvious resolution to this disagreement. Indeed, since Copenhagen the world seems to have moved further away from a global agreement, as indicated by the regular stoushes between Chinese and US negotiators. In my view, the divergence of views on this issue makes an international agreement highly unlikely, not this year, nor next, nor in any year soon.

The deadlock on an international treaty is a blow to international efforts, but not a knockout one. A less formal approach could be used, in which countries make individual efforts, apply peer group pressure to each other, and developed bilateral and regional trading and other cooperative links. This is the so-called bottom-up approach.

Although the bottom-up approach emerged at Copenhagen as a possible way forward, its development is threatened by a lack of leadership from the US. The most worrying climate change development this year has been the failure of the US Congress to commit the US either to an emissions target or to a carbon price. The famous cry at the 2007 Bali climate change conference was that if the US wasn't going to lead, it should at least get out of the way. This might work for international negotiations, but it won't for domestic action, as inaction by the US inevitably has a huge discouragement effect on other countries. There is no doubt that if the US had put a carbon price in place, then Canada would have one, and Australia. And then Japan and then Korea. It would be a circuit breaker. But since it didn't happen this year, it isn't going to happen in the near future, with the Republicans, dominated by climate change sceptics, taking control of the House. The US isn't inactive on climate change. Many states are taking action, the Federal government is supporting important technological initiatives, and the President has some powers under the Environmental Protection Act to regulate carbon dioxide emissions. But the US is not doing enough, and, importantly, is not perceived to be leading.

In essence, althought there have been some important positive developments over the last 12 months, this year has also seen the dashing of the two prospects on which most analysts hung their hopes for an effective international response to climate change: a new international agreement, and US leadership.

China's response

Climate change poses a geopolitical dillemma for China. It cannot freeride on the US, because the US is not leading. What then should it do? Should it allow the US to provide an upper bound on global ambition, and thereby ensure an inadequate global effort, or should China itself exercise global leadership on this issue, and thereby let the US off the hook? More generally, where the dominant superpower is not providing leadership on a key issue, how should the emerging superpower respond?

It is important to recognize the important contributions China has already made. China has already gone far beyond the expectations of many analysts in announcing a target which is both ambitious and unconditional. Prior to Copenhagen, many distinguished analysts assumed that China and other developing countries would have to be paid for any reduction in their emissions below business as usual. Jeffrey Frankel was a prominent proponent of the view that China and other major developing countries should take on business as usual targets, so that it could make a profit from any emissions efforts (Frankel, 2008). Such a view is supported by a literal interpretation of the United Nations Framework Convention on Climate Change, Article 4.3 of which famously guarantees developing countries that the "incremental costs" of their mitigation efforts will be covered by others.

China's commitment is not only not conditional on funding support from other countires. It is also not conditioned on the commitments made by other countries. Several developed countries, such as Japan and EU have put forward targets which are conditional on the efforts of others. Others, such as the US and Australia are yet to put forward definitive targets. China's target by contrast is already firm and operational.

What else might be expected from China? Three additional steps can be considered.

First, the biggest contribution China could make would be to make clear progress to its 2020 target. This would not only make a significant contribution to the task of global mitigation, it would also have a significant encouragement effect on other countries. Since the US cannot be persuaded to lead, perhaps our only chance is that it can be forced to follow. The onus for putting such a strategy in place must fall on other developed countries, but cannot be successfully executed by them alone. China has a critical role to play, as its stance will influence Washington more than that of any other country.

The second area where more could be expected from China is in the area of transparency. It is not clear to the outside observer why, even if in a regime honouring the central UNFCCC tenet of 'common but differentiated responsibilities', different reporting standards should apply to different countries. China could be given a grace period to give it time to do the technical work needed to meet global reporting standards. But it is hard to see why, once this period is over, the world's biggest emitter should not be required to meet the world's best standards for reporting and verification. China's low per capita income and relatively low per capita emissions require strong differentiation of its target from those of developed countries (for example, China should be allowed to grow its emissions in the immediate future, albeit at a slower rate than in the past), but it is hard to see how these factors should lead to the country being made subject to different verification standards.

Third, should China adopt a more flexible position in the international negotations, and drop its insitence on a second Kyoto Protocol commitment period? This would certainly be helpful for overcoming the current stalemate, but may be too much to ask for. One could imagine a grand bargain in which China dropped its insistence on a second commitment period for Kyoto in return for the US Senate adopting legislation on climate change. Unfortunately, due to US Senate intransigence, such a bargin is not on the table.

Conclusion

On the domestic front, China has put forward an ambitious mitigation reduction target. Achieving it will not be easy. The paper has highlighted three critical challenges which will need to be addressed if this target is to be achieved.

First, successful mitigation will require that energy prices rise significantly, whether through the introduction of a carbon price or other means. This is not an easy task for any country, and particularly not for one which still faces significant development challenges such as China. But it is critical not only for reducing emissions but for other important policy goals, in particular energy security.

Second, if carbon prices are to fulfil their potential as a mitigation instrument, reform of the energy sector will be required to allow cost pass-through. Reforms to allow a merit-order for generation dispatch, so that environmental as well as economic considerations can be taken into account, will also be important.

Third, mitigation will also require a rebalancing of the Chinese economy, away from investment towards consumption, to slow energy growth.

Other measures will of course also be needed (such as support for research and development, and other regulatory measures), but the three highlighted above will be the most difficult and have the most far-reaching consequences.

On the international front, the failure of the United States to provide leadership on the climate change issue makes for a bleak outlook. The fundamental international question facing China in relation to climate change mitigation is: is it willing to provide leadership on an issue on which the world's superpower is inadequately engaged? Looking forward, as China becomes more and more powerful, increasingly the world will look to it for leadership on important global issues. Climate change will be an important test case of whether China is prepared to rise to the challenge.

It is unrealistic to think that an international agreement can be reached without greater effort by the US. But there are other ways for China to show global leadership. The most important is for China to make serious progress towards its 2020 target. But China also needs to improve the transparency around its official energy and emissions figures, with a view to eventually submitting itself to the same reporting rules as other major global powers.

Successful mitigation is important for China not only because it will avert dangerous and potentially catastrophic climate change. Successful mitigation is also important because it will indicate that China is successfully dealing with its other major domestic and international challenges: that it is increasing energy prices, reforming the energy sector, rebalancing its economy, and assuming a greater responsibility for global leadership. Climate change mitigation is indeed a defining challenge for China.

References

Arnold, J 2008, "Do tax structures affect aggregate economic growth? Empirical evidence from a panel of OECD countries", OECD Economics Department Working Paper No 643, OECD, Paris.

Bacon, R, Bhattacharya, S and Kojima, M 2010, "Expenditure of low-income households on energy: evidence from Africa and Asia", *Extractive Industries and Development Series,* World Bank, Washington, DC.

Besant-Jones, JE 2006, "Reforming power markets in developing countries: what have we learned?", Energy Mining Sector Board Discussion Paper no.19, World Bank, Washington DC.

Burke, P 2010, "The energy supply ladder and its carbon implications", Australian National University, mimeo, August.

China Electricity Council 2010. *2015 年中国煤电装机将达9.33 亿千瓦 (China's coal-power generation capacity will reach 933GW in 2020),* available at http://www.cec.org.cn/news/showc.asp?id=132468.

Dechezleprêtre, A, Glachant, M, Hascic I, Johnstone, N, and Ménière, Y 2008, "Invention and transfer of climate change mitigation technologies on a global scale: a study drawing on patent data", *CERNA Working Series,* available at: http://ssrn.com/abstract=1414227.

Energy Information Administration (EIA) 2010, *International energy statistics,* US Energy Information Administration, available at http://tonto.eia.doe.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=2&pid=2&aid=7

Energy Modelling Forum (EMF) 2009, international database available at http://emf.stanford.edu/events/emf_briefing_on_climate_policy_scenarios_us_domestic_and_international_policy_architectures

Garnaut, R 2008, *The Garnaut climate change review*, Cambridge University Press, Cambridge.

Garnaut, R, Howes, S, Jotzo, F, and Sheehan, P 2009, "The implications of rapid development for emissions and climate-change mitigation", Ch. 5 in Helm, D and Hepburn, C (eds.), *The Economics and Politics of Climate Change*, Oxford University Press, Oxford

He, J and Kuijs, L 2007, "Rebalancing China's economy – modelling a policy package", World Bank China Research Paper No.7, September, World Bank, Washington, DC

Howes, S 2009b "Can China Rescue the Global Climate Change Negotiations?," Chapter 18 of *China's New Place in a World in Crisis*, Garnaut, R., Song, L. and Thye Woo, W. (eds) ANU E Press

Howes, S 2009b, "Sustaining growth and mitigating climate change: are the costs of mitigation underestimated?," paper presented to the July 2009 East-West Center Conference on Climate Change and Green Growth: Korea's National Growth Strategy.

Howes, S 2010a "The international effort on climate change: unravelling or shifting gear,", *East Asia Forum,* October 24, 2010, available at http://www.eastasiaforum.org/2010/10/24/the-international-effort-on-climate-change-unravelling-or-shifting-gear/

Howes, S 2010b, "China's energy intensity target: on-track or off?", *East Asia Forum*, March 31, 2010, available at http://www.eastasiaforum.org/2010/03/31/chinas-energy-intensity-target-on-track-or-off/

Huang, Y 2010, "China's great ascendancy and structural risks: consequences of asymmetric market liberalization", *Asian-Pacific Economic Literature*, vol. 24, pp. 65-85.

International Energy Agency (IEA) 2006, China's power sector reforms: where to next?, Paris.

International Energy Agency (IEA) 2008, *World energy outlook 2008,* Paris.

International Energy Agency (IEA), 2009a, *CO_2 emissions from fuel combustion, vol. 2009 release 01 -*, available at http://oberon.sourceoecd.org/vl=15178979/cl=15/nw=1/rpsv/statistic/s26_about.htm?jnlissn=16834291.

International Energy Agency (IEA) 2009b, *Energy balances of non-OECD member countries – extended balances*, Vol. 2009 Release 1, Paris.

International Energy Agency (IEA) 2010, *Energy prices and taxes – energy end-use prices, (US/toe, PPP/unit), Vol. 2010 release 02 -*, available at http://puck.sourceoecd.org/vl=16663138/cl=15/nw=1/rpsv/statistic/s29_about.htm?jnlissn=1683626x

Johansson, A, Heady, C, Arnold, J , Brys, B and Vartia, L 2008, "Tax and economic growth", OECD Economics Department Working Paper No.620, Paris, available at http://www.oecd.org/officialdocuments/displaydocumentpdf/?cote=ECO/WKP(2008)28&doclanguage=en

Lee, H (2010) "Regional mitigation costs from EMF22 models", Australian National University, mimeo.

Li, J 2010, "The economic effect of raising petrol product prices – application of SIC-GE", paper presented to the International Conference on the SIC-GE Model and Policy Simulation, 15-16 April, 2010, Beijing.

Mao, Y, Sheng H, and Yang F 2008, *The true cost of coal*, Greenpeace, the Energy Foundation and WWF, available at www.eu-china.net/web/cms/upload/pdf/materialien/TCOC-Final-EN-08_10-28.pdf.

Mercados–Energy Markets International (2010), *China power dispatch efficiency improvement: final technical report*, prepared for Energy Sector Management Assistance Program, World Bank.

Morse, RK, Rai, V and He, G 2009, "Real drivers of carbon capture and storage in China and implications for climate policy, Program on Energy and Sustainable Development, Working Paper no. 88, Stanford University.

National Bureau of Statistics of China 2010, *2009 China statistical yearbook*, China Statistics Press, Beijing.

Netherlands Environmental Assessment Agency [PBL] (2010) Database associated with Olivier, J, and Peters, J. "No growth in total global CO_2 emissions in 2009," Netherlands Environmental Assessment Agency, Bithoven, The Netherlands, available at http://www.pbl.nl/en/publications/2010/No-growth-in-total-global-CO_2-emissions-in-2009.html

Nordhaus, W 2008, A *question of balance: weighing the options on global warming policies*, Yale University Press, New Haven, Connecticut.

Outlook Economics (2010a) *China Energy Graphs*, Canberra.

Pahle, M 2010, "Germany's dash for coal: exploring drivers and factors", *Energy Policy* vol.38, pp.3431–3442.

PBL (see Netherlands Environmental Assessment Agency)

Rosen, DH, Houser, T 2007, *China energy: a guide for the perplexed*, The Centre for Strategic and International Studies, and Peterson Institute for International Economics, Washington, DC.

Rosenzweig, MB, Voll, SP, and Pabon-Agudelo, C 2004, "Power sector reform: experiences from the road", *The Electricity Journal*, pp. 16-18, doi:/10.1016/j.tej.2004.10.002.

SEI: See Stockholm Environmental Institute.

SERC (2006), *Electricity regulation report 2006* [*Dianli jianguan baogao (2006)*], State Electricity Regulatory Commission, Beijing, China.

SERC (2007), *Electricity regulation report 2007* [*Dianli jianguan baogao (2007)*], State Electricity Regulatory Commission, Beijing, China.

SERC (2008), *Electricity regulation report 2008* [*Dianli jianguan baogao (2008)*], State Electricity Regulatory Commission, Beijing, China.

SERC (2009), *Electricity regulation report 2009* [*Dianli jianguan baogao (2009)*], State Electricity Regulatory Commission, Beijing, China.

Sheehan, P 2008, "The new global growth path: implications for climate change analysis and policy", *Climatic Change*, vol. 91, nos. 3-4, pp. 211-231.

Stern, D and Lambie, R 2010, "Where is it cheapest to cut carbon emissions?," Environmental Economics Research Hub Research Reports 1063, Environmental Economics Research Hub, Crawford School, Australian National University.

Stockholm Environment Institute (SEI) and the Chinese Economists 50 Forum Stockholm 2009, *Going clean – the economics of china's low carbon development*, Gang, F, Stern, LN, Edenhofer, O, Shanda, X, Eklund, K, Ackerman, F, Li, L, and Hallding, K (editorial board), SEI, Sweden.

United Nations Development Program (UNDP) 2010, *China and a sustainable future: towards a low carbon economy and society*, China Human Development Report 2009/10, China Publishing Group Corporation, Beijing.

United Nations Framework Convention for Climate Change (UNFCCC), 2010, *Copenhagen Accord*, FCCC/CP/2009/ L.7, 18 December 2010.

Wadhwa, W, Gangopadhyay, S, Bacon, R, Kumar, P, Kojima, M, Lvovsky, K, and Ramaswamy, B 2003, *India: access of the poor to clean household fuels*, UNDP and World Bank Energy Sector Management Assistance Programme, available at: http://vle.worldbank.org/bnpp/en/publications/energy-water/india-access-poor-clean-household-fuels

Wang, Q, and Chen, Y 2009, "Energy saving and emission reduction revolutionizing China's environmental protection", *Renewable and Sustainable Energy Reviews*, vol, 14, pp 535–539.

World Bank 2010a, *Climate change and fiscal policy: a report for APEC,* World Bank, Washington DC.

World Bank 2010b, *Winds of change: East Asia's sustainable energy future*, East Asia and Pacific Region, East Asia Infrastructure Unit, Washington DC.

Wu, FF, Wen, F, Duan, G 2004, "Generation planning and investment under deregulated environment: Comparison of USA and China", Power Engineering Society General Meeting, 2004. *IEEE*, vol.2, p.1324-1328.

Zhang, C, and Heller, TC 2004, "Reform of the Chinese electric power market: economics and institutions", working paper no.3, Program on Energy and Sustainable Development, the Center for Environmental Science and Policy, Stanford Institute for International Studies, Stanford university, Stanford.

Zhang, J and Smith, KR 2007**, "**Household air pollution from coal and biomass fuels in China: measurements, health impacts, and interventions", *Environmental Health Perspectives*, vol. 115, pp. 848–855**.**

Zhao, L 2008, *Research on issue of electrovalent composing in China*, Masters' Dissertation (in Chinese), Dongbei University of Finance and Economics.

Zhou, N, Levine, M, and Price, L 2010, "Overview of current energy efficiency policies in China", *Energy Policy,* vol. 38*,* corrected proof, available at http://www.sciencedirect.com/science/article/B6V2W-4X5YWTS-3/2/e6e86707f0355f59689532b9639f933e)

Zissis, C, and Bajoria, J 2008, "China's Environmental Crisis", Council on Foreign Relations, available at: http://www.cfr.org/publication/12608/chinas_environmental_crisis.html.