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Going Clean – The Economics of China's Low-carbon Development

Stockholm Environment Institute and
the Chinese Economists 50 Forum

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Going Clean – The Economics of China's Low-carbon Development

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The project originated from discussions between the CE50 and SEI in the winter of 2006/2007 to establish an informal Chinese-international forum for dialogue and research between economists (including environmental specialists), as well as experts, scientists and policy makers concerning climate change and China's development. Led by CE50 and SEI, an inception meeting to initiate this process was held in Stockholm in February 2008, which identified key research issues and formed a research agenda. Targeted research was carried out, with scientific input from SEI, PIK, NERI and LSE Grantham Institute, culminating in 15 background papers. A mid-term review meeting was organised in Beijing in December 2008 to review the drafts of the background papers and discuss cross-cutting issues, and a final Global Forum was convened in Beijing in September 2009 to present and discuss key findings.

The project has involved, at different stages, a number of leading Chinese economists, and international economists working with climate change policies on a global level. Chinese economists: Liu He, Fan Gang, Wu Xiaoling, Xu Shanda, Justin Yifu Lin, Tang Min, Cai Fang, Hu Angang, Chen Dongqi, and Xie Ping. International economists: Lord Nicholas Stern, Ottmar Edenhofer, Frank Ackerman, Assar Lindbeck, Karl-Göran Mäler, Thomas Sterner, Kai Schlegelmilch, Laurence Tubiana, Tariq Banuri, Klas Eklund, and Yuichi Moriguchi.

This international collaborative research has involved a number of outstanding academics who are listed with their respective background paper on page 41. The background papers will be published in the spring of 2010, and can be obtained electronically in draft form from SEI.

SEI and CE50 would like to express their appreciation to cooperating institutions for this project: the National Economic Research Institute (NERI), China; the Potsdam Institute for Climate Impact (PIK), Germany; the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Germany; and the Grantham Research Institute on Climate Change and Environment, UK. Naturally, this project would not have been possible without the generous support of funding agencies: the Swedish Ministry of Environment; the German Federal Ministry of Environment; Shell (China); the UK Department of Energy and Climate Change (DECC); and the Rockefeller Brothers Foundation.

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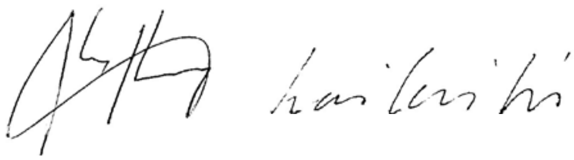
The work to synthesise the research findings into this report has been carried out by a drafting team lead by Karl Hallding. The drafting team has involved Klas Eklund (SEB); Helen Thai, Guoyi Han, Marie Olsson, and Sivan Kartha (SEI); Su Ming (Peking University), Cao Jing (Tsinghua University), and Gunnar Luderer (PIK).



Karl Hallding
Drafting team leader

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Stockholm and Bangkok, November 2009

PREFACE

The international community is increasingly recognising the risks of global warming caused by human activities. The estimated potential costs of non-action to climate change, based on available scientific research, are so high that any action to reduce carbon emission may be regarded as non-regrettable. Therefore, climate change can be seen as the defining issue of our age, as it may "rewrite the global equation for development, peace and security."[1] Our generation is at a crossroads, facing the greatest challenge of the modern, industrial era – to drastically reduce our reliance on fossil fuels while at the same time moving forward economic growth. China's participation, along with other rapidly emerging countries, and developed countries, is integral to any climate change solution.

To achieve this transformation to a low-carbon global economy, we need both better international cooperative mechanisms and new growth approaches and policy strategies for individual countries. China has already recognised the vulnerabilities of its ongoing pattern of economic growth and the need for low-carbon development.[2] Even in these difficult economic times, climate change action may present more opportunities than costs, for both developed and developing nations. China, like much of the world, would benefit from early mitigation efforts.

This report, *Going Clean – The Economics of China's Low-carbon Development*, is unique in delivering a common research partnership between the Chinese and international economic and climate change community. It is the result of a year-long collaborative research project by Chinese, Swedish, German, British and American experts to address some of the most challenging economic issues underpinning China's low-carbon transformation. The project, *Research and Forum on Economics of Climate Change: Towards a Low Carbon Economy in China*, was established by the Stockholm Environment Institute (SEI) and the Chinese Economists 50 forum (CE50). It is a joint effort to provide academic analyses and policy recommendations for the international community to improve cooperation on climate change and for the Chinese authorities to adapt economic policies and market instruments needed for the country to make an immediate, rapid and effective transition to a low-carbon economy.

Our report demonstrates that it is feasible for China to drastically reduce its carbon emissions in key carbon-intensive industries, while still maintaining economic growth and development aspirations. Moreover, these reductions can be achieved within the finite global carbon budget for greenhouse gas emissions, as determined by the hard constraints of climate science. *Going Clean* details the key economic instruments, policies and institutions which would enable China to cost-effectively reduce its emissions. Market mechanisms such as price liberalisation, carbon pricing, and a global carbon market, and inter-country joint mitigation plans need to be supported by substantial investment in clean technologies, and international finance and technology transfer. Such a transformation, for China and the rest of the world, will not be easy. But it is possible, necessary and worthwhile to pursue.

Johan Rockström
Executive Director
Stockholm Environment Institute

Fan Gang
Director
National Economic Research Institute

KEY CONCLUSIONS

- Developed countries are largely responsible for the climate change to date, but future responsibility is shared by developed and developing countries alike. Rapidly developing countries such as China with steeply rising emission curves must also actively participate in the much needed transition to a low-carbon economy. As the world's most populous country and the largest emitter of greenhouse gases, China's role is critical in combating global climate change.

- Although emissions reductions are needed in China, China is unable to shoulder the entire responsibility for achieving these reductions without technological and financial support. Burden-sharing frameworks – several of which are reviewed in this report – can assist in determining the allocation of each country's share of emissions reductions, as well as the allocation of permits under a global cap-and-trade regime.

- This report shows that China can achieve the transition to a low-carbon economy. China can make these emissions reductions within the tight constraints of a global 2ºC target while still meeting development and economic growth goals over the next four decades. There are strong mitigation potentials in the building, industry, transport and electricity generation sectors. China would benefit from early mitigation, but immediate action is critical for the world to have a reasonable chance of keeping warming below the 2ºC target.

- Such a transition would also be an essential part of China's modernisation. A low-carbon transition presents opportunities for China to improve its energy security and move its economy up the value chain in the production of international goods and services. A low-carbon China is a country with a larger service sector, more advanced labour skills and less environmental degradation.

- During this transition, new, green job opportunities will emerge, and support an overall shift to a low-carbon economy. Active labour market and social policies, vocational training and upgrading of skills are imperative to facilitate this modernisation and reduce the impact of jobs lost in resource-intensive industries.

- With today's low price on carbon emissions, the incentives for a low-carbon transition are not sufficiently strong. Consumption and production patterns must be steered in a more resource-sustainable direction. A first step is to phase out subsidies on fossil fuels. Another is to place a price on carbon, either through a carbon tax or a cap-and-trade system, which would create incentives for companies and individuals to produce and consume less carbon-intensive goods and services, and to undertake abatement opportunities to reduce their overall carbon footprint.

- Advancing technology and innovation need to be fundamental, shared policy objectives in this transition. Early investment reduces costs and paves the way for large-scale abatement. Carbon pricing mechanisms can also assist clean technology objectives, as anticipation of higher carbon prices sets an incentive to develop low-carbon technology and products, and can thus steer investments in this direction. In addition, we propose a new international finance mechanism – the Inter-country Joint Mitigation Plan – as a broader and more efficient way of financing technology transfers.

- There needs to be a substantial, stable and predictable source of international finance, accompanied by market reform and regulatory mechanisms that can recognise, support and deepen domestic mitigation and adaptation efforts. International assistance will fuel and accelerate China's shift to a knowledge-based economy.

- China faces a monumental challenge and a historic opportunity. The transition to a low-carbon society will require large investments but also bring about substantial benefits, not only to China but to the entire world.

1 THE CLIMATE CHALLENGE

Climate change is advancing, and its effects and risks are increasingly clear. Doing nothing is not an option. Unless the global economy is placed on a pathway to a low-carbon future, the impacts of climate change will damage growth and living standards to an extent far beyond that of the current economic crisis.

In our research, Nicholas Stern[3] emphasises the need for making climate change a priority. Postponing action on climate change, even for a few more years, increases the likelihood that we will be unable to hold greenhouse gas concentrations within the limits of acceptable risk, and makes mitigation more expensive in the future. This is largely due to the build-up of carbon-intensive energy infrastructure which, along with the long economic lifetime of investments, results in a lock-in to a global high-emissions trajectory. Even if we manage to limit the global temperature rise to 2°C, the socioeconomic impacts could be devastating: water stress for billions of people, mass loss of species and flooding of populous coastal cities.

It is within this context of increasing scientific evidence and the need for urgent action that this report makes its key point of departure. Combating climate change – and combating it now – is a shared global priority. The developed countries must lead, as they have committed to do under the Climate Convention.[4] But the participation of the developing countries – especially rapidly emerging economies such as China – is indispensable. Even if the world's developed countries were to make draconian cuts in their emissions, emissions in developing countries would need to be curbed significantly to keep atmospheric greenhouse gas emissions concentrations within acceptable levels. This report shows how it is possible for China, in co-operation with the world, to move to a low-carbon economy and put China on a route in line with a 2°C pathway.

1.1 SCIENCE SAYS: A FINITE GLOBAL BUDGET FOR GREENHOUSE GAS EMISSIONS

The hard constraints of climate science in determining a finite global budget for greenhouse gas emissions are clear. As recently presented in *Nature*,[5] to preserve a reasonable chance of keeping warming below 2°C requires limiting global carbon dioxide emissions to less than 1,000 Gt CO_2 between 2000–2050, for both land-based and fossil fuel-based carbon dioxide emissions. Since 2000, we have already emitted approximately 280 Gt CO_2 from the use of fossil fuels, leaving a carbon budget of 720 Gt CO_2 up to 2050. If heroic efforts are taken to bring deforestation and land degradation to a halt within one decade, then land-based emissions could be limited to approximately 60 Gt CO_2. We are therefore left with a global carbon budget of just 660 Gt CO_2 for fossil-fuels use over the next four decades (see figure 1).

The global carbon budget provides boundary limits for discussions on individual countries' share of the

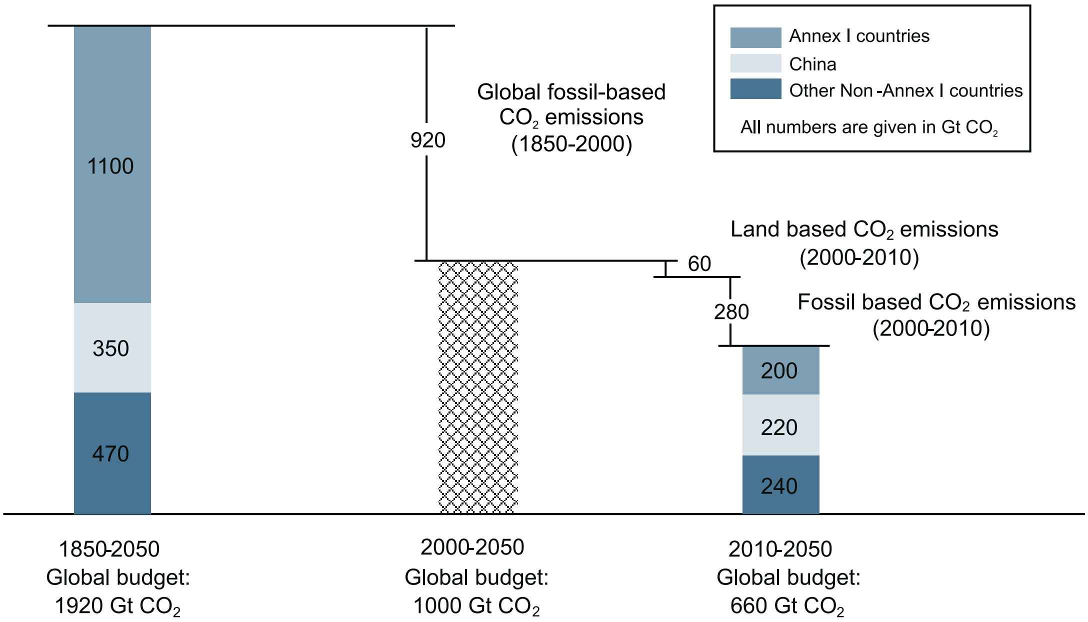

Figure 1: A global carbon budget

emissions budget, and highlights the sensitivity of changes to individual emissions budgets. For instance, if the industrialised (Annex 1) countries were to commit to more ambitious targets of reducing their emissions[6] to 40 per cent below 1990 levels by 2020, and 95 per cent below 1990 levels by 2050, their future emissions would amount to 200 Gt CO_2. This would leave 460 Gt CO_2 for the non-Annex 1 countries. If we assume that China's part of this remaining budget is proportional to its share of current non-Annex 1 emissions,[7] its future budget would be 220 Gt CO_2 (see figure 1).

This combination of scientific facts and simple arithmetic provides a reasonable – and bracing – estimate of the emissions budget available to China. While there is a range of possible emissions paths that would keep China within this budget, all these paths imply bold and ambitious action.

For example,[8] China's emissions could peak in 2015 and then decline at a rate of five per cent annually. Alternately, China's peak in emissions could be delayed to 2020, but would then need to be followed by a much more rapid decline of 11 per cent annually. If China's peak in emissions did not occur until 2025, the decline would need to occur at a virtually unattainable rate of 35 per cent every year. And, if the annual five per cent rise in emissions continues beyond 2026, the full budget of 220 Gt CO_2 will have been expended. While each path requires unprecedented mobilisation, it is clear that the longer that transformation to a low-carbon economy is delayed, the less feasible it becomes (see figure 2). As shown in chapter 3, the transformation is indeed feasible, but will have to be launched in the very near future.

There are two further points that must be emphasised about this arithmetic exercise: firstly, while this simple arithmetic exercise tells us that emissions from China must be rapidly curbed to address climate change, it does not tell us how the effort required to do so should be shared. Financial and technological resources will be critical for a low-carbon transformation to occur, and China is unable to bear the burden of generating and providing all those resources on its own. The same, of course, goes for other developing countries. The allocation of that effort among nations will need to be based on historical and political context, and grounded in the principles of equity that are clearly embodied in the United Nations Framework Convention on Climate Change (UNFCCC). In other words, the fact that China's *emissions* must be sharply curbed does not mean that China's *emission rights* have to be similarly curbed. The discrepancy between the two would then have to be covered by a commensurate amount of financial and technological support.[9] This support could be implemented through a global cap-and-trade system, where developed countries buy emissions rights from China, and China receives financial resources in return. This would provide China with an economic incentive to sell a portion of its emissions rights, and follow a more ambitious emissions trajectory domestically.[10]

Secondly, the above calculation is based on a target that still entails risks that warming will exceed 2°C. There is a strong scientific case to be made for adopting a more restrictive goal with lower risk for climate change impacts. [11] Delaying climate change mitigation also increases the need for more forceful action on climate change further down the track, and large-scale deployment of mitigation technologies to meet these targets. The key message here from a climate science and risk management perspective is that early mitigation not only reduces the costs but also the risks of delayed climate change action.

Rising to the global climate change challenge will require a concerted, coordinated, and committed response from the entire international community. Governments will need to lead the charge in formulating a long-term strategy, and create the institutions, mechanisms, incentives for technological innovation and market environment to carry it out. It is vital that these conditions are established soon, in order to guide the expectations of both investors, who will have to make critical long-term commitments, and decision-makers, who determine policies at sub-national levels. Citizens, too, can make lifestyle changes that will enable transition to a low-carbon world.

The message is loud and clear, the world needs to act now and act together, and China has a key role to play.

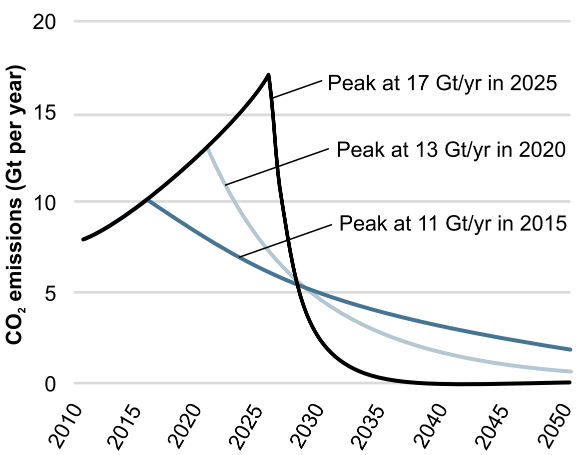

Figure 2: Carbon reduction scenarios for China with different peak years and a budget of 220 Gt CO_2 from 2010–2050

1.2 CHINA'S SUSTAINABILITY CHALLENGE IN THE CLIMATE CHANGE CONTEXT

Since the start of economic reforms in the late 1970s, 30 years of rapid economic growth in China have brought prosperity and reduced poverty. China is today the second largest economy in the world, when measured in purchasing power parity terms, and its economic growth has followed a resource-intensive path similar to many developed countries. China managed to slow down emissions growth in relation to economic growth considerably between the 1980s and the end of the century. But despite the overall decline in emissions per unit of economic output, China is today one of the most energy- and carbon-intensive economies. At the same time, China faces many serious sustainability challenges that affect its ability to respond to the challenge of climate change.

China's economic growth has come at a high social and environmental cost, and there is a rapidly widening gap between the rich and poor, placing additional pressure on already scarce and unevenly distributed resources. China's macro-economic structure has a high dependency on the coal and industrial sectors, and export strength in low-value goods. This means considerable challenges for China to quickly transform its developing economy to a low-carbon, knowledge-based economy.

China is attempting to modernise at a time when climate change mitigation is moving up the international agenda, and it will have to find fuels other than coal, gas and oil for its economic growth. This will require massive structural transformation for China, not only of its energy mix, but also of its energy-intensive transport and building sectors. No country has previously taken on a modernisation process as extensive as the one China is currently struggling to balance.

The speed of China's modernisation process adds stress to the task of simultaneously managing domestic, energy-intensive development and global climate change mitigation. China knows too well its own vulnerability to climate change impacts, from increased extreme events like flood and drought, to melting glaciers and water shortages, to reductions in key grain production. Climate change impacts will reverse years of development gains, and act as environmental and economic constraints on China's ability to modernise. Thus, seeking a low-carbon development path is not just *an* option for China, but *the only* option.

A global low-carbon transformation will be practically viable and politically acceptable only if it does not compromise development and growth in developing countries. China is clearly still a developing country, with per capita emissions less than half of the Annex 1 average, and only one-quarter of US levels. Viewed in terms of cumulative contributions to climate change, this contrast with industrialised countries is even more stark, with China's per capita contribution less than one-fifteenth that of the US.

However, China's contribution to the climate problem is undeniable. The country as a whole currently accounts for almost a quarter of global CO_2 emissions and makes up almost 60 per cent of the global increase in carbon emissions within this decade. China's per capita emissions have now risen above the world average. In our research, Fan *et al*.[12] show that China's historical contribution to CO_2 in the atmosphere may still be comparatively small, but this is changing rapidly as its emissions grow. China will exceed its share of global cumulative emissions at some point in the next two or three decades, in the absence of mitigation measures beyond 'no-regrets' policies.[13,14]

China realises that addressing climate change brings profound economic and developmental opportunities. In modernising, China can absorb lessons learned from developed countries. Increasing energy efficiency and reducing its reliance on exported fossil fuels will increase China's energy security and international economic competitiveness.

China's present climate change policies are heading in the right direction, and it realises that addressing climate change in the framework of sustainable development is in line with its national strategic interest, and would bring tremendous benefits for the environment, health, long-term energy security, and for many other areas. From the guiding principle of the Scientific Outlook on Development,[15] to an extensive set of laws and regulations, to major national programmes and policies, China has started on the road towards a low-carbon future. It continues to invest a significant amount of money in climate change mitigation and adaptation, and has enhanced its efforts in the current fragile economic environment.

However, more needs to be done by all. China in partnership with the rest of the world will need to embark on a new era of closer financial, technological, and institutional cooperation if global emissions are to be reduced sufficiently to hold the increase in global temperatures below 2°C.

1.3 THIS REPORT

This report, and the background papers which it builds on, has been developed under the project *Research and Forum on Economics of Climate Change – Towards a Low-Carbon Economy in China* (see Acknowledgements). The project has addressed the issue of how China could 'bend the curve' from that of the trajectory followed by most countries in their development process towards that of a low-carbon development path (see box 1). In this project we address some of the most challenging macro-economic issues concerning climate change mitigation for China, such as: what are the key policies that can support domestic growth while at the same time placing China on a low-carbon pathway? How can the economic and social costs of mitigation during a transition to a new economy be contained? How can China best foster the opportunities of low-carbon growth?

This report summarises the project achievements and presents the research results in a broader policy context. The report does not aim to provide a prescriptive blueprint for climate policy, but instead to contextualise China's climate challenges and to provide research and analysis on the policy options for China and their feasibility. Our research has covered:

- comparative cross-country analysis of the relationship between emissions and living standards;
- examination of alternate burden-sharing frameworks for determining China's share of emissions reductions, including a Chinese proposal for a consumption-based burden-sharing concept;
- development of a deep carbon reduction scenario to demonstrate the feasibility of, and conditions for, reducing carbon emissions in China;
- analysis of two major mitigation mechanisms, carbon tax and carbon trade, and their implications for China;
- exploration of economic measures to mitigate the negative effects of China's shift to a low-carbon economy;
- discussion of policies and mechanisms to increase innovation, technology transfer and investment in a low-carbon China, including a proposal for a new regime for international cooperation on technology transfer.

This report attempts to bridge gaps in economic research on climate change policies for China. Still, more work needs to be done, and throughout the report we have identified particular areas for further research. Key areas include:

- *Implementing a low-carbon transformation:* Specific sectoral policy and reform measures to enable China to simultaneously best-capture opportunities of future comparative advantage, scientific and economic development, dynamic growth, and technology innovation. Additional areas for study include China's building, transport, industry and energy sectors – all of which hold clear mitigation potential, but also industries where transformative change is difficult to implement. Further research on regulatory measures to remove market barriers that prevent consumers from responding efficiently to carbon price signals.
- *Social resilience and adaptability to, and support for, a low carbon transformation:* Social and labour market policies and public participation policies to facilitate a low-carbon transition in China. These include policies to avoid or offset regressive distributive impacts of a low-carbon transition, including through transportation, housing, land-use, and revenue recycling policies. Research into the requirements for strengthening China's social resilience and adaptability, to improve the effectiveness of domestic low-carbon policies.
- *Carbon market instruments:* Research gaps include China's institutional and administrative capacities to implement and expand carbon market instruments, their integration with other policies, and international cooperation in these areas. Such research could analyse the social and economic implications of various policy measures, and appropriate compensation mechanisms to mitigate negative social and economic effects.
- *Low carbon pathways*: Not withstanding the deep carbon reduction scenario developed in this report (see chapter 3), there could be further development of alternate pathways for China to achieve environmental, developmental and economic growth aspirations. Future research could include cost estimates for each scenario and distinct narratives leading to alternate policy directions.

Although the climate change policies explored in this report are grounded in an economic context, it is important to remember the limitations of cost-benefit

Box 1: Bending the curve – China's carbon emission challenge

Figure 3 illustrates a range of emission projections for China that have been assessed by different international and Chinese institutions and research groups. These projections can be categorised into three groups:[16]

- At the top end of the range there are *business as usual (BAU) scenarios* which presuppose that China's development will continue with no or only small technology gains and at near constant energy intensity.
- In the middle range there are a number of *baseline* or *reference scenarios* which lie above the trajectory that would be the result of successful implementation of policies to reduce China's carbon intensity by 25 per cent per five-year period i.e the energy-efficiency scheme set up by the present.
- Finally, there is a group of *deep reduction scenarios* which are based either on backcasting how much reduction is needed in China to keep global temperature within the 2°C target.

The range of projections shows both the opportunity to make considerable progress towards climate security in China and the importance of coming to an international agreement that will enable China to harness the significant opportunities for continued development while slowing down emission growth.

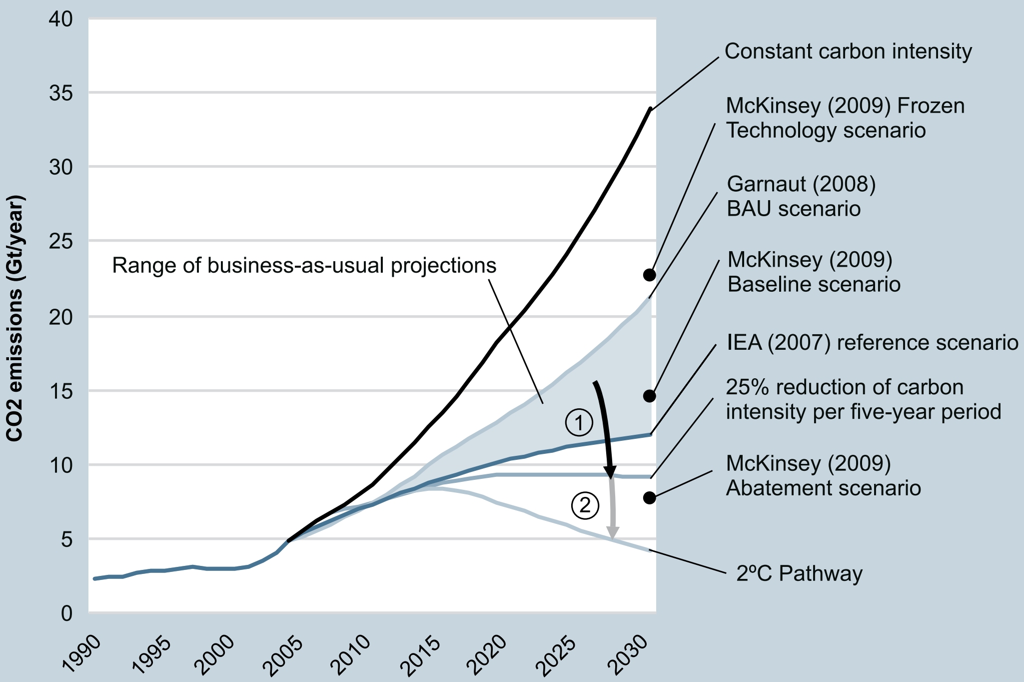

Figure 3: Schematic overview of possible future emission pathways for China[17]

The first arrow ① illustrates the considerable curb of carbon emissions that China's current ambition to reduce energy intensity and switch to non-fossil fuel would imply if it were extended to 2030.[18] The second arrow ② shows how much more would be needed for China to reach a low-carbon emission trajectory in line with what would be needed for the world to meet the 2°C target.

principles. For instance, cost-benefit calculations may not properly account for the risk of large or catastrophic climate change damage, or the vital non-market impacts of climate change that a price cannot be placed on, such as health impacts, stress of physical relocation, or secure access to clean water.[19]

The remainder of the report is structured as follows: chapter 2 explores the meaning of a fair global deal, and reviews different perspectives in terms of their implications for China's share of emissions rights. It lays the groundwork for examining the nature of the international financial and technological cooperation that will be needed to enable China to undertake a low-carbon transformation. Chapter 3 seeks to illustrate the nature of that transformation from a technological perspective, showing that it is feasible, if it is launched promptly. It looks at the implications of a low-carbon strategy in various sectors, including building, transportation and electricity generation.

Chapters 4 and 5 focus on some of the policy options that China and the international community face as we look to a low-carbon future. Chapter 4 explores some of the key market mechanisms and institutions for pricing, regulating and trading carbon, while measures to foster domestic and international innovation and investment are discussed in chapter 5. The final chapter wraps up the report with an examination of the modernisation task facing China.

2 THE NEED FOR A FAIR DEAL

Meeting the global climate challenge must start from the increasingly alarming scientific evidence of climate change, as well as an understanding that development for the disadvantaged must not be compromised. In this chapter we search for an understanding of how China and the global community could act together to put China on an emissions pathway that is consistent with scientific advice on climate change, while allowing for continued poverty alleviation and increased living standards.

2.1 EMISSIONS, LIVING STANDARDS, AND CONSUMPTION

Our research by Flaschland *et al.*[20] shows that most of the carbon emissions to date have occurred in the industrialised countries, and there is a strong link between historical emissions and accumulation of wealth (see figure 4). Our research by Stanton[21] analyses the dilemmas and complexities in the relationship between living standards and emissions. Climate change impacts are becoming increasingly serious as a result of rising greenhouse gas emissions. But these same emissions have been essential to maintaining high-consumption lifestyles in rich countries and progressing development for poor and middle-income countries.

The case of China illuminates a difficult issue of international equity: how can the international community balance each individual's right to an adequate standard of living with the imperative of reducing global greenhouse gas emissions? Bluntly speaking, only the poorest countries have per capita emissions that are currently on a level that is commensurate with a long-term global 2ºC target. Countries with higher standards of living, not just measured in terms of private consumption but also by life expectancy and literacy, show much higher emissions per capita.

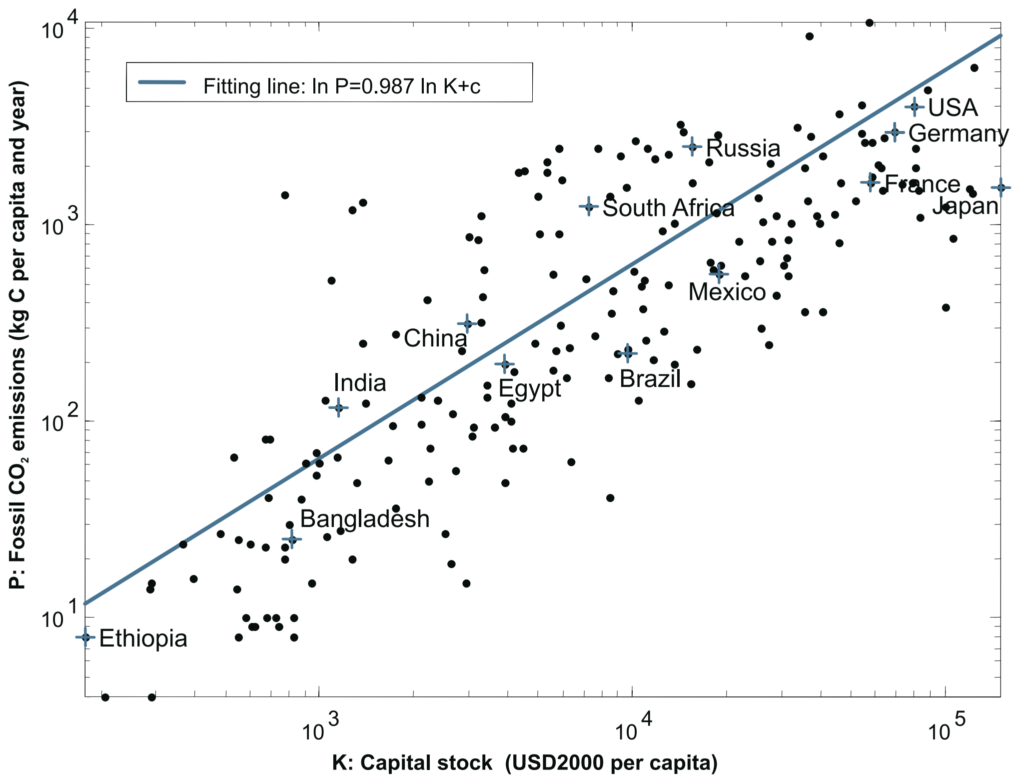

Figure 4: Correlation between wealth (capital stock) and accumulated per capita emissions. (Capital stock is defined as the investment over the past 20 years, with 5 per cent depreciation)

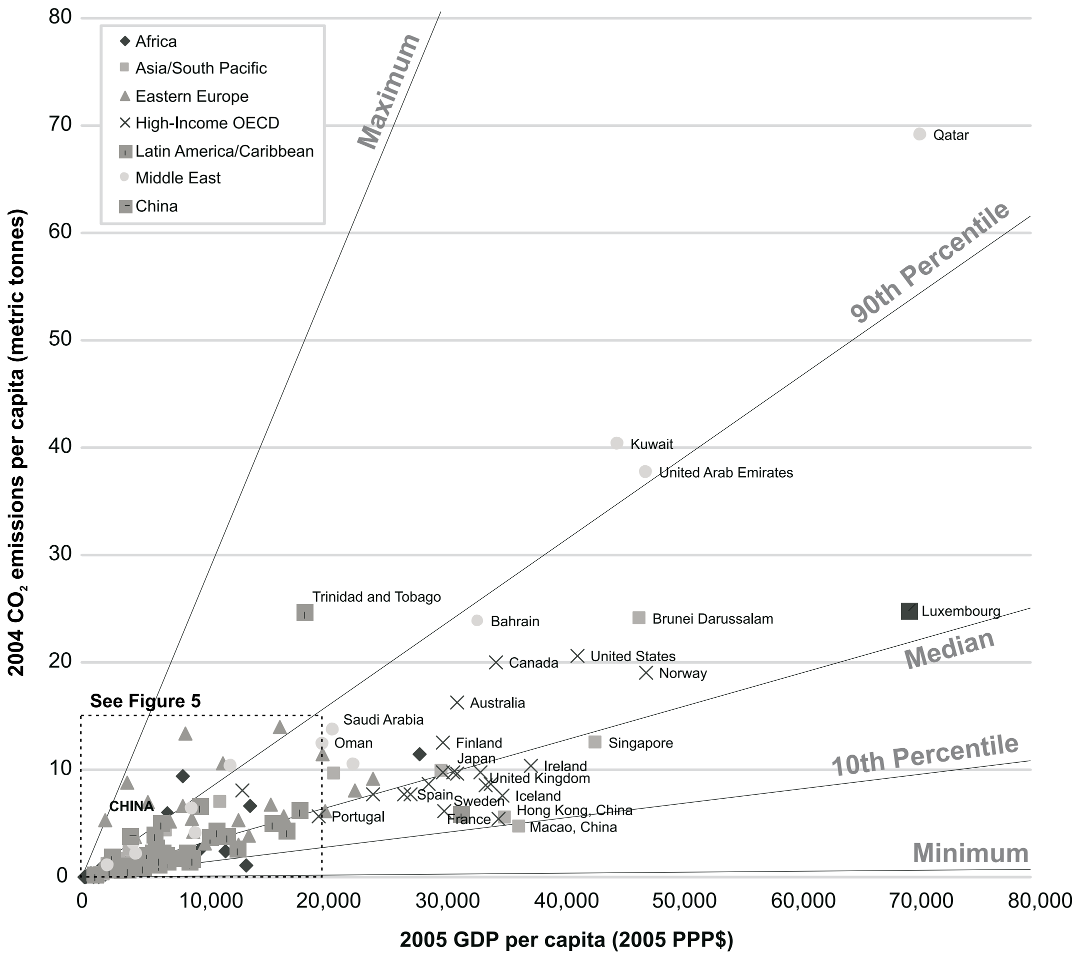

Figure 5: Emission per capita against GDP per capita (purchasing power parity figures): all countries[25]

While there is great diversity in development levels within China, its average per capita emissions are today already higher than the world average.[22] For countries below China's emissions per capita, the trend is clear: greenhouse gas emissions are highly correlated with the level of development. Above China's level of per capita emissions, improvements in life expectancy and literacy are slow, but gains in income per capita remain strong.

Although there have been remarkable gains in energy efficiency and carbon intensity throughout the reform period, China still belongs to the ten most carbon intensive economies in the world.[23] Figures 5 and 6 show that few countries share the Chinese provinces' high emissions intensity with a similar range of income per capita.[24]

What can China learn from its own development?

The three richest provinces in China – Tianjin, Beijing and Shanghai – all have considerably higher per capita emissions than China as a whole. As the most developed regions in China, these provinces should be those most able to transform to a low-carbon economy. Yet their relatively high emission levels foreshadows a considerable rise in per capita greenhouse gas emissions as China continues to urbanise – far above levels compatible with the global 2ºC target. At the same time, it is apparent from comparing Beijing with its surrounding Hebei province that it should be possible for China to raise per capita income levels considerably with only small emission increases. Yet, the Beijing/Hebei example indicates a future for China of roughly seven tonnes per capita, which is far above the global levels compatible with the global 2ºC target.

A more positive example is provided by China's two Special Administrative Regions, Hong Kong and Macau. Both have shown consistent income development with only limited growth in per capita emissions – despite the fact that energy supply relies almost entirely on fossil fuels. Part of the explanation for this low energy intensity lies in high population density, abundant public

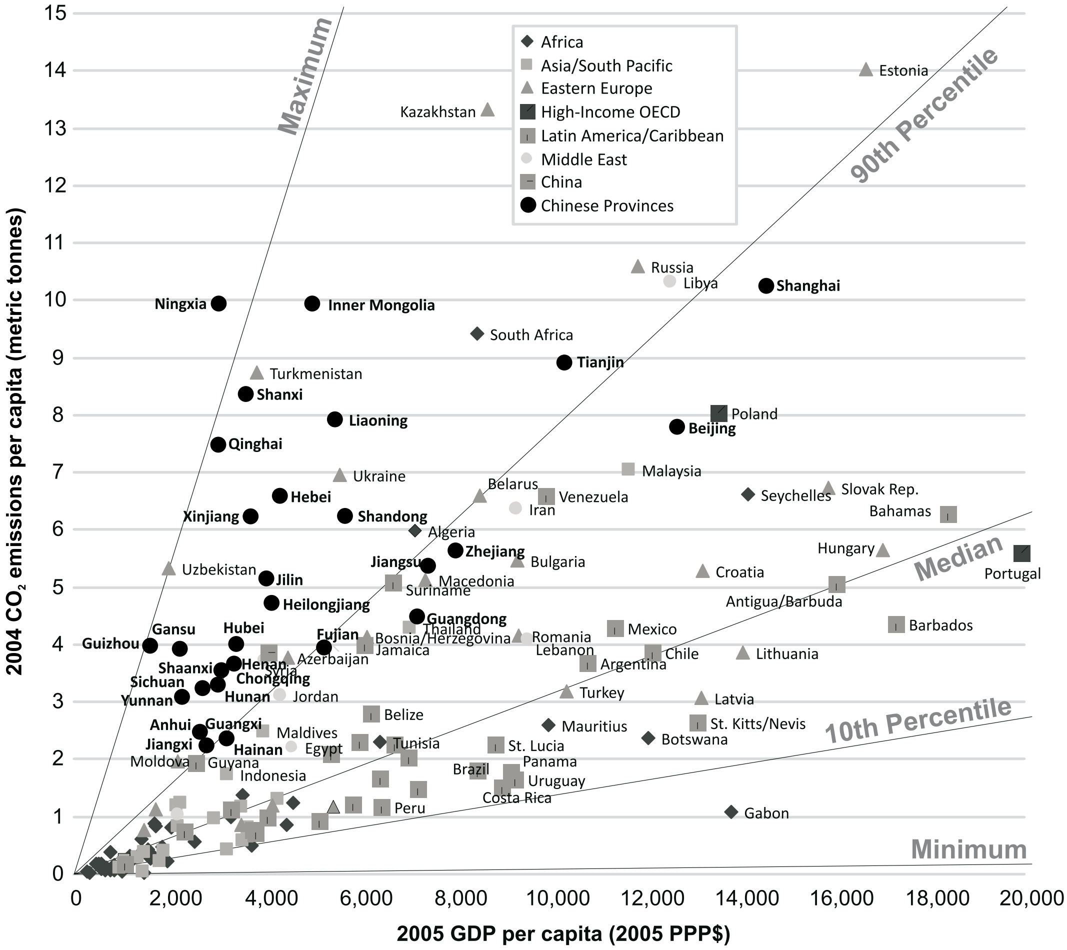

Figure 6: Emission per capita against GDP per capita (purchasing power parity figures): Chinese provinces and similar countries (below)[26]

transport and a service-based economy. The remarkable difference between Hong Kong and Macau on the one hand, and other prosperous urban areas in China (e.g. Shanghai, Beijing and Tianjin) could also be partly explained by the fact that a considerable part of the wealth of the former (particularly Hong Kong) is built on manufacturing that takes place in Guangdong province. Still, the combination of Hong Kong, Macau and Guangdong province would add up to an economically more diverse entity with per capita emissions at around five tonnes per capita. This is better than the examples provided by the Beijing/Hebei example above.

What can China learn from other countries?

In order to stand a reasonable chance to keep within a 2ºC target, global per capita emissions must decrease steadily throughout this century from current roughly four and a half tonnes to well below four tonnes by 2020, less than two tonnes by 2050 and roughly half a tonnes by 2100. If global emissions are to decrease over time two things will be necessary: first, rich countries must cut their per capita emissions drastically; and second, low-income and middle-income countries must find ways to increase their per capita incomes while maintaining or reducing emissions intensity.

One conclusion is clear from this analysis: there are no examples of high-income countries with per capita emissions low enough to serve as a blueprint for a low-carbon development path. The high-income countries with the lowest emissions, such as France, Sweden, and Switzerland, are still at about six tonnes per capita. These countries also share the trait of producing a higher share of energy from renewables and nuclear. China's plans to ambitiously expand the share of non-fossil fuel energy sources are important steps in this direction.

Historical growth trajectories for individual countries, based on Gapminder analysis, show a wide range of different development pathways. Several countries – albeit developed ones – have bent their emissions

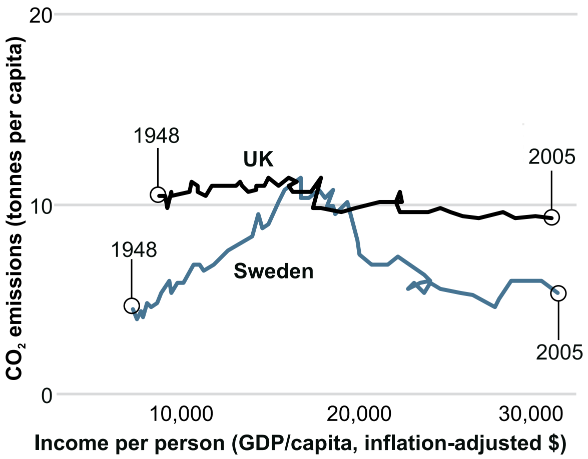

Figure 7: CO_2 emissions and income per capita for Sweden and the UK, 1948-2005[27]

curve downwards or contained emissions levels while still increasing per capita income levels. For example, as can be seen in figure 7, the UK and Sweden have shown positive emissions trends in important sectors, and policy has played a crucial role in reducing emissions while at the same time creating space for growth. The causes for these reductions in emissions differ between Sweden, where a nuclear programme and carbon tax have played important roles (see box 4), and the UK, where fuel switching from coal to natural gas was a key factor. However, although this indicates promising opportunities, it needs to be emphasised that for cases like Sweden, where absolute emissions have decreased since the 1980s while incomes increased, the emission cuts have to some extent been offset by increasing imports of embedded carbon.

But more importantly, there are an increasing number of positive stories on carbon reduction from sectors, cities or regions where considerable progress towards low-carbon transformation is being demonstrated. We provide several case studies in chapter 3.

Consumption, carbon emissions, and the new global order of production

As noted above, Sweden and the UK, along with many other countries around the world, have used the increased income generated by growth to consume more imported goods. And here is where China comes into the picture. Over the last decade or two, China has dominated the global increase in production capacity, particularly for consumer products. The main reasons for this have been comparative advantages in factors such as labour costs and productivity, as well as China's accession to the World Trade Organization (WTO) in the early 2000s. During the same period China acquired a huge net surplus in embedded carbon exports, which has led to suggestions that China benefits from its carbon-intensive production. In our research Ackerman shows that China does not have comparative advantages in carbon-intensive exports. Instead the embedded carbon in China's exports is a consequence of how high carbon intensity rubs off on its trade surplus.

The result of these circumstances is that the combination of low-cost and high energy-intensity production in China (and other countries) has become a significant contributor to global carbon emissions.

Questions, reflections, and the consumption dilemma

The relationship between consumption, emissions, living standards, and how globalisation has reorganised production, contains crucial knowledge for our understanding of how the world might be improved for all, and for solving the climate dilemma. Further investigation in this area is needed, but based on our research (Ackerman[28]) and other work done by SEI outside of this project,[29] we can identify two key issues.

Firstly, to the extent that China continues to supply the world with consumer products, consumption-based per capita emissions in importing countries will only decrease if China can reduce its overall carbon intensity. Ackerman (see chapter 4) concludes that the incentive for high-income countries to support China in lowering its carbon intensity would be stronger if consumers were responsible for the carbon emissions embedded in import products. This would help to promote policies leading to joint goals of global low-carbon development. The most effective mechanism to ensure that costs are transferred to consumers is through the market, which supports the argument that both China and high-income countries should increase efforts to establish carbon-market instruments, and to help build China's capacity to work effectively with such instruments. Chapter 4 will analyse various domestic and international market mechanisms for pricing carbon.

Our second conclusion is far-reaching and potentially more ambiguous. As noted above, the limited emissions reductions shown in some high-income countries, such as Sweden and the UK, are offset by increasing private material consumption. Therefore the question must be asked: can the target of restraining a rise in global temperatures to below 2ºC be attained if there are no effective policies to radically reduce material consumption? And conversely, if such policies were in place, what would that mean for poor countries in terms of their development opportunities?

This report does not examine this dilemma in depth, and there is certainly a need for further research. However, a few reflections can be offered. Once a basic level of living standards has been reached there is no clear relationship between material consumption and quality of life. Still, consumption plays a central role for maintaining and fuelling economic growth. Policy measures to take the world out of the predicament of consumptive growth, driven by fossil-fuels, will have to establish incentives for growth through non-material consumption while at the same time providing opportunities for poorer countries to increase consumption in order to meet basic needs. It will be particularly important to make existing technologies available, and to research, develop and implement cutting-edge low-carbon technologies that are appropriate for use in developing countries.

2.2 FRAMEWORKS FOR BURDEN SHARING

Climate change raises serious questions about global equity in reducing emissions. Any meaningful solution to the climate crisis must induce an urgent and sweeping transformation of the global emission trajectory. This will be practically viable and politically acceptable only if it does not compromise development and growth in developing countries. Well-off people, wherever in the world they live, will have to accept taking on a larger responsibility for the global climate transition, so as to safeguard the right to development for the most disadvantaged.

An institutional framework with the power to bring about the urgently needed transformation of the global emission trajectory (i.e. as discussed in chapter 1), has to reflect both equity (taking into account different countries responsibilities for the climate crisis, and capabilities to mitigate emissions and respond to climate impacts) and cost efficiency (reducing emissions and responding to impacts at the least total cost for the global community). A number of frameworks for burden sharing have been developed that propose how countries might agree on allocating obligations within a global climate regime. Each framework applies different distributional principles which affect the emission rights of different countries and financial flows between countries. Different principles often put forward in the discussion of allocation rules include:

- egalitarian (same rights to every person);
- ability to pay (capacity to contribute to the mitigation effort); and,
- polluter pays principle (accounting for historic responsibility for greenhouse gas emissions).

Each of these principles provides a basis for allocating access to a global commons resource. As such, they come into competition with a fourth principle – the principle of sovereignty. Sovereign countries tend to privilege their own short-term national interest and to resist joint management of common resources. This is often expressed (often implicitly) as an appeal to the principle of a ‘customary right to emit’. While this is a strong force within the climate negotiations, it provides little basis for a long-term solution to any problem of sharing a common resource.

Specific proposals for allocation can be characterised by the relative importance they assign to distinct principles, and none will satisfy them all. Several approaches have emerged, each based on its own set of principles, each with different implications for different countries. For this research effort, we have reviewed a set of key proposals with respect to their implications for China’s emissions allocation. The proposals we have reviewed are as follows:

- *Equal Per Capita Emission Rights.* A straightforward approach premised on the equal rights to the atmospheric commons, where all countries would be awarded emission permits in proportion to their population, which they would be free to trade.[30]
- *Grandfathering*. The direct expression of the “customary right to emit” whereby countries allocations are determined by granting all countries permits in proportion to their prior emissions, constrained by an overall decline in global emissions consistent with the temperature target.
- *Contraction and Convergence (C and C)*. A hybrid framework combining grandfathered emission rights with per capita emission rights, with a gradual transition from the former to the latter over a specified number of decades.[31]
- *Equal Cumulative Per Capita Emission Rights.* Extends the concept of equal per capita rights

to cover the entire carbon budget, rather than just the portion of the budget remaining for the future.

- *The Indian Proposal.* A proposal whereby India's per capita emissions would not exceed developed country emissions. Up to that point, its emissions allocation is equal to its baseline requirements.

- *Greenhouse Development Rights (GDR).* This proposal shares burdens among countries according to capacity and responsibility, with each of these defined with respect to a development threshold so as to explicitly safeguard a right to development.[32] We have also modelled variants of the GDR's approach, as developed by Fan *et al*.[33] (See box 2 for details of the GDR's approach.)

Among these proposals, a distinction can be made between *resource sharing* and *effort sharing* approaches. *Resource sharing* approaches, such as the equal per capita emission rights, grandfathering, and contraction and convergence, assume a limited global greenhouse gas budget and define rules for allocating this resource. However, some resource sharing approaches have the difficulty to account for historical responsibility and ability to pay.

Effort sharing approaches, such as the Greenhouse Development Rights, seek to equitably share the effort required to reach the climate target. They can directly take into account historic responsibility and the ability to pay, but have to rely on the definition of a baseline against which the reduction effort can be measured.

2.3 WHAT IS CHINA'S FAIR SHARE OF GLOBAL EMISSIONS REDUCTIONS?

Figure 8 shows the emissions rights that would be conferred to China under different burden-sharing frameworks. The most notable feature of this analysis is that the three well-known resource sharing frameworks (the Indian Proposal, Contraction and Convergence, and Grandfathered emissions, all shown in light blue) would all allocate *fewer* emissions rights to China than would be sufficient to cover even the very demanding emission pathway needed to keep China within the 2°C budget (outlined in chapter 1). In other words, expressed in terms of a global cap-and-trade system, China would under these frameworks be a net purchaser (rather than seller) of emission permits. It would need to invest its own resources in reaching the 2°C-consistent pathway, as well as purchase permits from other countries that have excess permits.

Also shown (in dotted black) are two different versions of equal cumulative per capita allocations, one of which equalises per capita emissions since 1850, the other since 1950. The choice of year from which cumulative per capita emissions are equalised is an important parameter, and, as would be expected, the later the year the lower China's allocation. As figure 8 shows, both versions allocate fewer emission rights than the International Energy Agency (IEA) reference scenario for China, but more than would be needed to meet the 2°C-consistent trajectory. In other words, China would be expected to invest its own resources in a certain amount of mitigation, but would be able to rely on international resources for the remainder.

Box 2: The Greenhouse Development Rights (GDR) Framework

The GDR framework aims at ensuring on the one hand that global emissions are capped and cut to meet the 2°C target, while on the other that developing countries' right to development is safeguarded. It defines burden-sharing in a manner that shields from all climate costs those individuals who fall below a specified 'development threshold'. People below this threshold are taken as having development as their overriding priority, and thus have no carbon reduction obligations. People above the threshold are taken as having realised their right to development and obligated to help preserve that right for others.

The GDR calculates the burden-share of countries by quantifying *responsibility* and *capacity*. Responsibility is interpreted as the contribution to the climate problem; and capacity as financial wherewithal to invest in climate solutions. The indicators for responsibility and capacity are greenhouse gas emissions and income levels, respectively. The GDR differs from conventional approaches in that it interprets both of these indicators with respect to the development threshold. More specifically, it defines capacity as *income above the development threshold*, and responsibility as *emissions corresponding to consumption above the development threshold*.

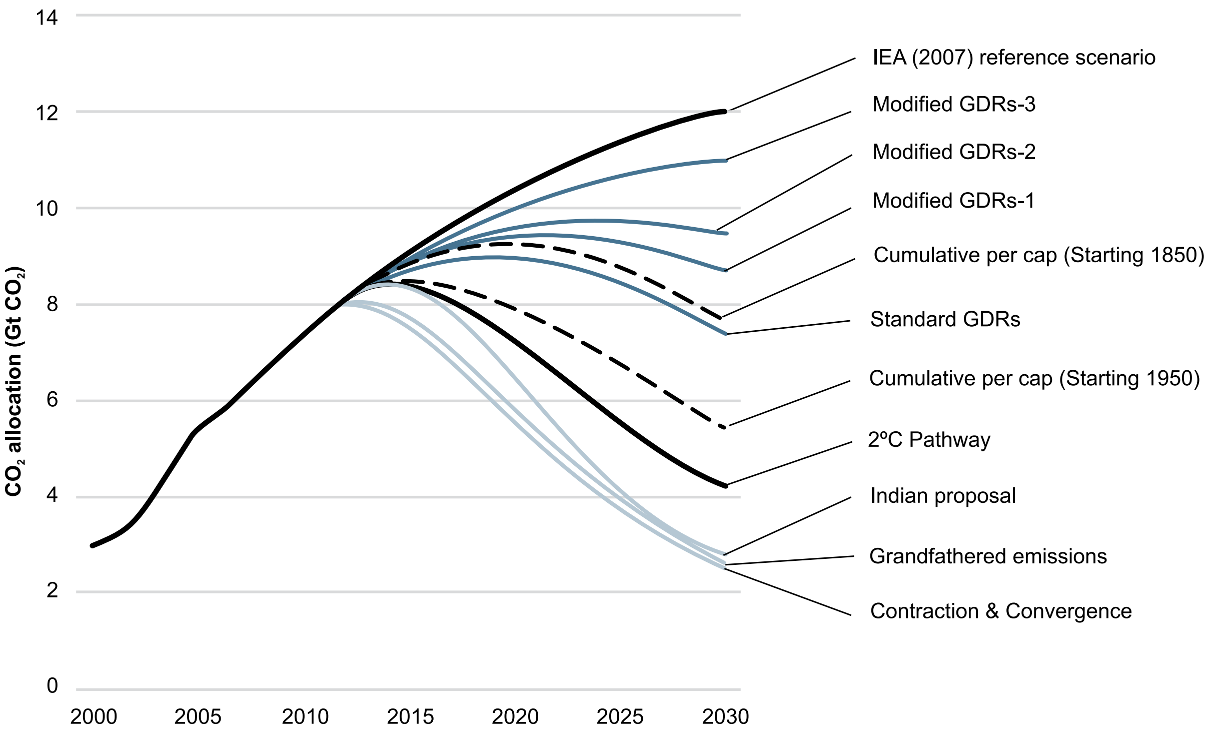

Figure 8: Emission allocations for China under various frameworks[34]

Also shown (in dark blue) are a set of variants of the Greenhouse Development Rights (GDR) framework. The GDR approach explicitly allocates obligations in terms of capacity and responsiblity, defined with respect to a development threshold (see box 2). Figure 8 shows four trajectories based on different variants of the GDR framework, each of which defines differently the capacity and responsibility of countries. The most stringent of the trajectories (the bottommost dark blue line) reflects the standard GDR analysis as presented by Kartha.[35] Three main modifications that soften the demands on China have been proposed by Fan *et al*.[36] The first of these moves the historical responsibility back to 1850, rather than 1990 as in the standard GDR analysis (GDRs-1). The second modification introduces consumption-based accounting, adjusting for emissions embedded in internationally traded goods (GDRs-2). The third corrects the carbon intensity of the domestic energy mix by using an average global carbon intensity (GDRs-3). These modifications, taken together, reduce China's share of the global obligation for reducing global emissions by roughly a factor of three.

Although the differences between Fan's and Kartha's results are not trivial, the range of GDR variants all yield emission rights for China that significantly exceed what China's emissions would be under the 2°C pathway. This contrasts sharply with the three resource-sharing regimes (shown by the light blue lines) and means that under the GDR variants a large portion, if not the overwhelming majority, of emissions reductions in China would be eligible for support from international sources. This underscores that a burden-sharing regime that is focused on explicitly safeguarding a right to development ultimately places significantly less of the burden on the developing countries, including China, and correspondingly more on the industrialised countries.

The equity implications of a burden-sharing regime rely not just on its underlying principles, but also on the mechanism through which it is implemented. Two types of mechanisms in particular can be highlighted. A market-based cap-and-trade systems allow permits to be purchased on an open market at a price that reflects a marginal abatement cost. A managed fund, on the other hand, would direct resources to mitigation opportunities in different countries based on their actual incremental costs of abatement, rather than global marginal price set by a market.

Provided they have a large-enough regional coverage, cap-and-trade systems have the advantage that they can provide cost-efficient emissions reductions by allowing abatement to be performed where it is cheapest. However, as our research by Flachsland *et* *al.*[37] shows, some countries will be able to reduce emissions at a cost lower than the global price at which carbon allowances trade. Countries that are net sellers of permits under a global cap and trade system would thereby benefit from "rents" – allowance revenues that exceed their actual costs of emissions abatement.

The lower a country's mitigation costs relative to the global trading price, and the larger the volume of allowances it is able to sell, the greater the rents it will earn. Unless a burden-sharing approach explicitly takes this additional benefit into account, its outcome could differ appreciably from the underlying equity principles on which it is based. Certain burden-sharing approaches, (e.g. equal cumulative per capita emissions and the Greenhouse Development Rights variants), result in comparatively large volume of allowances sales, since there is a large difference between the allocation of emission allowances and the ultimate distribution of physical emissions. Implementing such burden-sharing approaches in part through a fund-type financing mechanisms would be required to avoid the excessive rents that would occur in a carbon market.

2.4 A 'GRADUATION THRESHOLD'

As part of their modifications of the GDR framework, Fan *et al*.[38] have developed a specific recommendation regarding when the onset of binding commitments might be justified for China. Their proposal suggests that countries above a 'graduation threshold' for emissions should automatically face compulsory mitigation. This threshold is defined as the level of accumulative consumption emissions per capita of the Annex 1 country with the lowest level of such emissions (currently, this happens to be Romania). Countries below the graduation threshold could pursue voluntary mitigation activities, but would not be compelled to mitigate.

Such voluntary mitigation would delay the point when the threshold is crossed and mitigation becomes compulsory. If a country accepts international technology and financial transfers, its graduation threshold would be increased. Under this proposal, it would be possible for China to delay by a few years mitigation through legally binding means, provided that China devotes itself to voluntarily mitigating its energy intensity by 20 per cent under its 11th five-year programme, and pursuing this target into its 12th and 13th five-year programmes (2011–2020).

In this context, however, it should be noted that if a functioning global carbon market is established, most countries – including China – would actually benefit from early mitigation. This is because they can participate in the market for emission rights (i.e. to gain revenue from selling such rights) and that the risks decrease of being locked-in to expensive emission-intensive investment.

In any event, any meaningful effort to protect the climate will require ambitious mitigation action to be undertaken in China even *before* the onset of binding reduction commitments. If this is to occur, that action will have to be supported and enabled by technology and financing, based on the commitments of industrialised countries. A fair and equitable burden-sharing framework can help to clarify not only what levels of domestic mitigation countries must undertake, but just as importantly what levels of financial and technological support they must provide.

3 THE ART OF THE POSSIBLE – A DEEP CARBON REDUCTION SCENARIO

A development pathway to a low-carbon economy, although challenging, would be feasible for China to achieve. The scenario presented here is one of several possible scenarios to radically reduce China's current emissions. What makes this deep carbon reductions scenario (DCRS) so ambitious is that it is an attempt to drastically cut emissions while at the same time allowing China to grow rapidly and expand the material welfare of its population.

The DCRS demonstrates the *technical* feasibility of reducing China's emissions to a level that is compatible with protecting the planet. At the same time it gives enough 'emissions space' for China to continue to develop. In this scenario, emissions are decoupled from GDP growth; while production and income continue to grow, emissions are reduced.

3.1 THE DEEP CARBON REDUCTION SCENARIO

In our research, Heaps[39] shows how China can meet development and economic growth goals over the next four decades, while at the same time keeping greenhouse gas emissions within the very tight budgets of a global 2ºC target (see box 3).

Given the overall momentum for growth and development in China, and the lack of availability of technologies that can be deployed immediately on a large scale, it is simply inevitable that China's emissions will continue to climb in the next decade, even under the most ambitious of mitigation scenarios. This makes the requirements for reducing emissions later particularly challenging.

Our analysis shows that a deep carbon reduction scenario is technically feasible with strong mitigation potential in the buildings, industry, transport and electricity generation sectors. The result of successful capture of mitigation potential in these sectors is shown in figure 9.

The net result of implementing the four groups of measures in the buildings, industry, transport and electricity generation sectors is that total energy sector emissions are lowered dramatically compared to the baseline scenario. The deep carbon reductions result in energy sector CO_2 emissions peaking in about 2017 at 7.4 Gt CO_2 per year, before falling to 1.9 Gt CO_2 per year in 2050. Cumulative emissions between 2005 and 2050 are 229 Gt CO_2: consistent with the budget deduced for China from the carbon budget exercise reviewed in chapter 1. Annual CO_2 emissions intensities show a similar shaped curve, growing from 3.6 tonnes per capita in 2005, peaking in 2016 at 5.3 tonnes per capita, and then falling to only 1.3 tonnes per capita in 2050 – clearly in line with what is necessary on a global scale.

3.2 CONSTRUCTION

The construction sector has huge potential for mitigation of CO_2 as rapid urbanisation and development in China continues to maintain high demand for building construction. Policy action is critical in this sector to avoid lock-in effects for future generations, particularly as rates of construction can be expected to decline as China's population peaks, its workforce ages and its economy matures.

Energy intensities in the construction sector can be reduced dramatically. Energy intensity reductions can be achieved through measures including:

- better design of new buildings to incorporate passive heating and cooling principals;
- retrofitting of existing building shells to reduce heating and cooling loads;
- more efficient heating, ventilating and air conditioning systems;
- efficient lighting;
- introduction and enforcement of stringent appliance efficiency standards for such as refrigerators, washing machines, dryers, and TVs; and,
- improvements in the construction of buildings (e.g. to use more sustainable and less energy-intensive building materials).

Of these measures, improved building design has the largest long-term potential and the best economic benefit-cost ratio. The construction sector can also be largely decarbonised by replacing direct use of fuels (e.g. driving a car on gasoline), with greater use of electricity, excess heat, and solar energy.

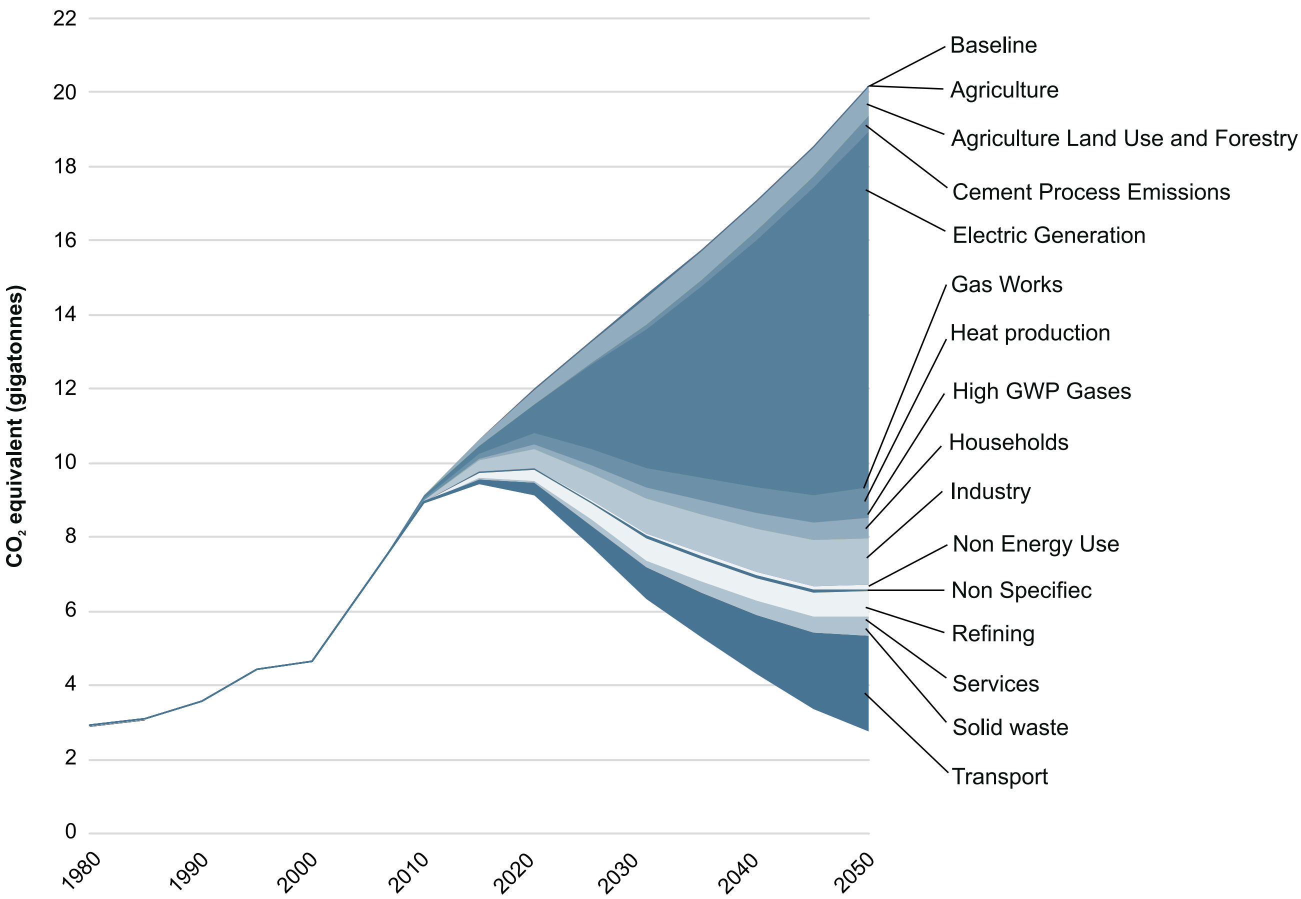

Figure 9: CO_2 emissions in baseline and deep carbon reduction scenarios

The mitigation benefits of energy intensity improvements in the household and services sectors would be further magnified through changes in the fuels used in the buildings sector, with a nearly complete shift away from coal, oil and natural gas in favour of electricity, district heating, and solar energy (the latter primarily for hot water). As explained further in this chapter, this shift away from small-scale combustion of fuels can be coupled with a dramatic decarbonisation of electricity and heat production. In the DCRS, a significant level of biomass fuel use is retained, reflecting the development of cleaner, more efficient and more convenient ways of using biomass fuels in rural households. In the service sector there is also potential for the near-complete phase out of fossil fuels, to be replaced by electricity, heat and (to a smaller extent than in the residential sector) solar energy.

3.3 TRANSPORT

Emissions from China's transport sector are rising rapidly. Increasing income leads ever more households to purchase cars and travel, while efficiency improvements in business practices and the industrial supply system (e.g. through just-in-time deliveries) are increasing total emissions output. If continued population growth and increased production result in a similar trend in emissions from transport, China's emissions budget will not hold.

The DCRS assumes three potential major shifts in transportation policy. Firstly, we expect policies to slow the rapid overall growth in passenger transportation. The DCRS assumes a range of actions, such as higher fuel prices, improved urban planning to reduce the need for commuting, congestion charging, a revitalisation of cycling, parking restrictions, and restricted airport developments.

Secondly, the DCRS assumes that, contrary to baseline trends, rail and road transport will retain their current shares of the transport sector. This implies increased public awareness and use of public transport to constrain rising car use. Road transport as a share of total passenger kilometres is assumed to stay roughly

Box 3: What is the deep carbon reduction scenario?[40]

The DCRS examines the feasibility of massively reducing China's CO_2 emissions in 2050, to only 10 per cent of the 2005 levels projected in a baseline scenario. Expressed in terms of figure 9, the DCRS is the combined result of low-carbon technology options across a range of sectors. This pathway for China is designed to match China's 2ºC pathway outlined in figure 3, and to stay within an overall emissions budget for energy sector emissions of about 230 Gt CO_2 between 2005 and 2050. This budget for China's emission is consistent with the global emission pathway presented in chapter 1.

The scenario focuses on mitigation technologies that are either already commercialised or are expected to become commercialised in the next decade, in time that their deployment will have a significant impact in reducing China's emissions. However, given the long time horizon, this development necessarily includes far-reaching assumptions about the degree and direction of technological change. For instance, we assume that energy intensity will continue to decline rapidly, particularly for the period after 2030, which inevitably implies a massive and sustained level of research and development.

The DCRS and the baseline scenario assume a general continuation of current policies which include some significant efforts to address sustainability and the climate challenge, but it does not foresee any fundamental shifts in energy policy. Both scenarios rely on a similar set of assumptions about structural changes in China's economy: for instance, that the share of GDP coming from services is projected to increase from 40 per cent in 2005 to 52 per cent in 2050; that the share from agriculture decreases markedly from around 12 per cent in 2005 to only 2 per cent in 2050; and that the share from industry stays almost constant going from around 47 per cent in 2005 to around 46 per cent in 2050.

The baseline scenario relies upon a sector by sector review of historical trends, as well as an examination of how future energy and CO_2 emissions patterns can be expected to evolve as China develops and average income levels increase. Up until 2030 the scenario closely matches trends in energy use and CO_2 emissions foreseen in the IEA's World Energy Outlook 2008 for China.[41] Additional analysis has been done to extrapolate energy and CO_2 emissions patterns out to 2050.

It is important to understand that the deep carbon reduction scenario is not a proposal about the level of obligation that China should take on in any international climate negotiations. Nor is it a proposal about what financial burdens different parties should carry, or a prescriptive technology or policy roadmap. The scenario presented in this chapter is not intended to represent a least cost development path. Other positive economic effects, such as innovation, comparative advantage, technological leadership, and export gains are discussed throughout the report.

A range of alternative pathways could potentially yield the same total emissions. But these alternative pathways would need to be much less materials intensive. This can be achieved either by lowering the economic growth ambitions or by drastically changing the composition of growth, emphasising the provision of welfare more through the delivery of services than through the consumption of goods. For example, they might include less consumption of meat, more consumption of vegetables, better urban planning to reduce the need for transport, and more emphasis on health care and environmental protection. The net result of these measures would be a smaller industrial sector but a larger service sector with a consequent lowering of energy and greenhouse gas emissions. China's choice in the development pathway it takes will partly depend on the priorities it places on social needs, consumption of goods, equity of welfare and income distribution and other policy objectives.

constant even as the total passenger-km value grows enormously – by a factor of 3.75. The share of road transport made up by buses is also assumed to stay roughly constant. Similarly, the rail share of passenger-km is assumed to decrease only slightly from 35 per cent in 2005 to 30 per cent in 2050. Again, because of population growth, this represents a huge increase in absolute terms from about 606 billion pass-km in 2005 to about 1,900 billion pass-km in 2050 in rail transport. This would be a high value for a developed nation, but not unprecedented. The share for air travel, both domestic and international increases from 12 per cent in 2005 to 15 per cent in 2050, below the 18 per cent reached in 2050 in the baseline scenario.

The third shift, and perhaps the most challenging of all, is a massive move away from dependence on oil-based internal combustion engines toward electrification of passenger road transport. Such a transition could happen in a number of ways, but will likely follow a gradual path through hybrids and plug-in hybrids to fully electric vehicles. In the DCRS, this is modelled as a gradual transition that would begin slowly in about 2015, ramp up after 2030 and culminate in 2050 with 90 per cent of all road passenger-km being delivered by electrical vehicles. The transition from oil to electricity not only yields a significant decarbonisation of transport, it also yields important efficiency benefits.

Similar but much less dramatic transitions are assumed for freight transport. In addition to these fundamental shifts the DCRS also assumes modest penetration of biofuels in the air travel and maritime sectors. Finally, in terms of rail transport, we assume the complete phase-out of coal-fired railways, and a complete transition by 2030 to electric powered trains. Furthermore, gradual efficiency improvements are predicted for rail travel due to the introduction of new technologies such as regenerative breaking.

3.4 INDUSTRY

In China, industry is the largest consumer of energy, accounting for 55 per cent of final energy consumption. Compared to the baseline scenario, the DCRS assumes more concerted efforts to improve energy efficiency and switch to lower carbon fuels wherever possible.

Iron and steel

In the iron and steel sector, large emissions reductions can be achieved with the use of electric arc furnaces for steel production. Notwithstanding efforts to switch to such modern techniques, traditional coal-based Basic Oxygen Furnace production will remain important in China given the country's reliance on coal. Here, reductions in emissions will have to rely on energy efficiency improvements as well as carbon capture and storage. We assume energy intensity improvements of 30 per cent per tonne of steel by 2050 combined with carbon capture and storage for the CO_2 generated from 50 per cent of oxygen furnace-produced steel by 2050.

Cement

In the coming decades, a number of options are available to reduce emissions from the cement industry. These include a more rapid and complete switch to the advanced and less energy-intensive dry-process pre-calciner kilns; further reductions in the clinker-to-cement ratio (to reduce the overall need for cement in concrete); the use of carbon capture and storage for up to 50 per cent of cement kilns by 2050; and the limited use of low-carbon agricultural residues or biofuels for co-firing of kilns. In the longer run a number of new technologies are being researched for the production of new 'eco-cements' that could potentially reduce emissions more dramatically. However, as these processes are only design concepts at present and face significant hurdles before they can be commercialised, they have not been included in our scenario. Nevertheless, there is reason to think that cement production could be significantly decarbonised beyond 2050 and perhaps even before.

Other manufacturing

In other manufacturing sectors – chemicals, non ferrous metals, transport equipment, machinery, food and tobacco, paper and pulp, wood and wood products, textiles and leather – our DCRS projects energy consumption using fairly simple assumptions. Industrial energy intensity in 2050 in this scenario is only 47 per cent of its starting value in 2005. This assumption of a 53 per cent reduction is clearly optimistic, but it is not without precedent, especially in China where IEA statistics suggest that, in the 25 years since 1980, energy intensity in the major industrial sectors other than cement, and iron and steel, have been reduced by between 50 per cent and 90 per cent. Of course these reductions may reflect the gathering of 'low hanging

Box 4: Sweden – Thinking outside the carbon box[42]

Sweden shows it is possible to combine economic growth with reduced emissions, although as noted earlier, part of its emission cuts are offset by increased imports of embedded carbon. Nevertheless, in the 1980s emissions decreased largely due to a government-led expansion of nuclear power and a carbon tax. Furthermore, since 1990, greenhouse gas emissions in Sweden have fallen a further 10 per cent, while GDP has increased by nearly 50 per cent. Switching energy systems and energy efficiency improvements are key drivers behind this trend.

For instance, energy for heating residential and service sector buildings is largely sourced from renewable biomass and waste, combined with efficient combustion and gas heat recovery. By exploiting surplus heat from industry, Swedish companies achieve substantial energy and cost cuts. Industrial waste heat is supplied by forest industries, refineries, steelworks, and chemical and food-processing industries.

fruit' and the benefits of economies of scale that cannot easily be repeated. But it is at least possible that the reductions assumed in our DCRS can be engineered in the coming 40 years if the international political will emerges to do so. Coupled with these assumptions on future intensity improvements, the scenario examines the potential within each sector for switching to lower carbon fuels, based largely on an acceleration of past trends toward greater use of electricity and central production of heat. In two sectors – paper and pulp, and wood and wood products – the scenario also assumes the use of biomass and agricultural residues. Carbon capture and storage is not assumed to be viable in sectors other than the largest and most carbon intensive sectors: cement, and iron and steel.

Dematerialisation

In addition to improvements to energy efficiency, there is a variety of opportunities for China to begin to pursue less material-intensive forms of development. Dematerialisation implies that a larger fraction of GDP will come from services and light industry and a smaller fraction comes from the more energy and carbon intensive heavy industrial sectors. However, despite the mitigation potential of dematerialisation in China, this has not been assumed to occur as part of the DCRS. This is because such shifts might not necessarily imply genuine dematerialisation – they might simply imply that production shifts away from China to other perhaps equally carbon-intensive nations, whilst material consumption in China continues to increase. Such a transition would in fact be replicating how most OECD nations have grown in recent decades – apparently reducing their energy intensities, even while substantial amounts of production have been shifted overseas (much of it to China).

3.5 ELECTRICITY GENERATION

The fourth and most difficult area for policy intervention is China's energy supply – specifically its electricity generation sector – which is heavily coal dependent. Here, the DCRS includes a massive undertaking to decarbonise the supply of electricity and heat to the fullest extent possible given China's resource base. This pathway is designed to work in tandem with efforts on the demand side to eliminate the localised combustion

Box 5: Rizhao and Baoding– Chinese cities embracing renewable energy

Rizhao[43]

In Rizhao, a city of three million people in Shandong province, northern China, a shift to renewable energy has resulted in a halving of CO_2 emissions. As of 2007, 99 per cent of Rizhao's households are using solar-power heaters, most street lights are powered by photovoltaic cells, and solar water heaters must be integrated into the construction of all new buildings. This shift has been made possible due to government policies that encourage solar energy use and provide financial support for research and development. Local solar-panel industries have also capitalised on the opportunity to improve and popularise their products.

These environmental improvements have been achieved alongside a growing economy. Between 2001–2005, GDP growth rate for Rizhao averaged 15 per cent per year – implying almost a doubling of income level in only five years. By comparison, the average growth was 13 per cent in the broader Shandong province over the same period. The improved environmental profile of Rizhao may also have helped attract high-profile universities to the city, rapidly increase foreign direct investment and boost the travel industry.

Baoding[44]

Baoding, a city of 10 million people in Hebei province, south of Beijing, has transformed itself from a city reliant on the automobile and textile industries into the fastest-growing hub of solar, wind, and biomass energy-equipment makers in China.

Since 2002, nearly 200 renewable energy companies have emerged in Baoding, some of which are now among China's biggest manufacturers in their fields. Baoding now has the highest growth rate of any city in Hebei Province: in 2007, Baoding's GDP grew by 17 per cent, with the renewable energy sector contributing 12 per cent of this rise. Within the next two years, the renewable energy industry is forecast to overtake the auto and textile sectors as the city's most important engine of growth, and by 2050 is expected to contribute 40 per cent of the city's GDP.

Like Rizhao, Baoding's economic shift was enabled by a combination of factors. Its growth as a hub for the renewable energy sector was supported by government policies that included targeted tax benefits for companies and investors. The local government also provided subsidies for residential areas that adopt solar power.

of fossil fuels and replace them with electricity and centrally supplied heat.

Early retirement of existing inefficient coal-fired electricity generation. The DCRS assumes the accelerated retirement by 2045 of all existing coal, oil- and gas-fired power plants. Since a large proportion of these plants were built in the current decade during China's most rapid phase of economic expansion, this represents the early retirement of a significant level of electricity generating capacity. It is an expensive proposition, but essential for keeping China's CO_2 emissions within the overall budget specified for the scenario.

Large-scale deployment of efficient coal-fired power with Carbon Capture and Storage (CCS). The DCRS assumes that all new coal plants built from 2010 onwards will be much more efficient than the current stock of coal-fired power plants. The average efficiency of new coal plants is assumed to be 43 per cent, versus the roughly 29 per cent average efficiency of the current stock. The DCRS assumes that CCS will not be available until 2020, but after that date all new power plants are assumed to use a CCS system that captures 90 per cent of the CO_2 emitted by the plants. These plants are expected to operate at a lower efficiency (39 per cent) due to the energy needs of the CCS process. In addition, by 2050, 90 per cent of the existing power plants built between 2010 and 2020 are assumed to be retrofitted for CCS capture. Under the DCRS it is also predicted that fewer natural gas plants are constructed than in a baseline scenario, and that these plants are subject to the same assumptions about CCS.

Large-scale development of non-fossil energy. The DCRS assumes that large amounts of new power will be generated from wind (offshore as well as onshore), solar energy (concentrating solar panels and solar photovoltaic), municipal solid waste and biomass, and small hydropower plants. Given the growing resistance to large-scale hydropower schemes, the capacity for these plants is assumed to be the same as in the baseline scenario. Finally, the DCRS also takes into account the potential for significant increases in nuclear power. While nuclear power is still unpopular in parts of the world, mainly due to concerns over nuclear proliferation, safety, waste management and storage, it is included in the DCRS because of its potential for CO_2 mitigation and the preference shown for this technology by policymakers in China.

Combined heat and power generation. The DCRS also assumes that all new thermal power plants will be designed for the combined production of both heat and power, as well as operating at greater efficiencies. By 2050, 25 per cent of all energy inputs to thermal and nuclear plants are assumed to be captured as usable process or district heat. This is likely to be hard to achieve, particularly since many power plants will be built away from the potential consumers of heat. However, this assumption is key to lowering emissions since it allows an essentially zero-carbon resource (waste heat) to be used to meet the increasing need for energy in China's industrial sector. Such a scenario is only likely to be plausible if future industries and power plants are developed in a much more integrated fashion.

3.6 MANAGING THE CHALLENGES AND DISRUPTIVE EFFECTS

Two key points are clear from our research: firstly, if the DCRS is to be achieved, the expected challenges are massive. All of the elements identified in our scenario must happen: electrification of vehicles, massive deployment of renewables, a complete switch to CCS based coal-fired generation, huge improvements in energy efficiency, significant changes to passenger transportation modes, and so on. Although extremely ambitious, the DCRS would only barely remain within an emissions budget that matches China's 2ºC pathway. Consequently, a loss of any single major element would make it impossible to reach these mitigation goals.

Secondly, time is short. Not only do all of the options need to be implemented, but they also need to happen quickly. Any delay in implementing options will make it almost impossible to meet the overall target budget of 230 Gt CO_2. Furthermore, the later the peak in carbon emissions, the more difficult it will be for China to comply with the emissions budget.

A drastic reduction of carbon emissions, such as proposed in our DCRS, is a strategy of forced retirement of existing capital and replacing it with new forms of capital that are technologically, socially and institutionally advanced. In the spirit of Joseph Schumpeter, this process could be described as 'creative destruction' or 'forced disruption'. This process, especially on the scale required for ambitious climate action, is likely to also have disruptive effects. Central to these concerns are the anticipated job losses in existing heavy industry, such as would occur from the early and large-scale retirement of much of China's existing power sector, and the costs of mitigation and adaptation.

Box 6: Cities around the world aiming for zero emissions

Munich, Germany
A study of Munich,[45] a city of 1.3 million inhabitants, has found that Munich could use cost-effective measures to transform itself into an almost carbon-free city over the next five decades. Moreover, such a shift is possible without any fundamental change in the standard of living of its residents. Ways of reducing carbon emissions include better insulation in buildings, more efficient heating and power generation systems, energy-efficient appliances and lighting systems, and a changeover to renewable and low-carbon power plants. Government policies can encourage consumers to invest more consistently in environmentally-friendly, cost-effective technology and to increase their use of environmentally-friendly transportation.

Tangshan, China[46]
Tangshan municipality in eastern north China is traditionally a centre of heavy industry, based on steel production and coal resources. At the start of its efforts to achieve a circular economy (one which balances economic development with environmental and resources protection), the city used Caofeidian island, 80 km from the Tangshan city centre, as a proving ground for realising new development visions. Construction is now under way of a new eco-city for 1–1.5 million people, in conjunction with a new industrial zone that will host heavy industries previously located in Tangshan. The eco-city's buildings will be climate-neutral and self-sustained with renewable energy resources. The Swedish company Sweco was commissioned to undertake the project, and the work will be underpinned by advanced environmental technology solutions. An ecological park will also be constructed to allow public access to Caofeidian's unique ecosystem.

Masdar, United Arab Emirates[47]
By 2016 Masdar city, in the middle of the desert in the United Arab Emirates (UAE), is projected to be entirely carbon free. The city intends to create a silicon valley for green technologies that will host 1500 companies, 40,000 residents and 50,000 commuters. The city also aims to use 100 per cent renewable energy, implement building design that incorporates passive heating and cooling, and roll out transport powered by renewable energy. Cars will be banned in favour of a city design that encourages walking, and the introduction of high-technology solutions such as Personal Rapid Transit and Freight Rapid Transit. Furthermore, it is hoped that awareness raising and behavioural change will reduce energy consumption by 25 per cent relative to comparable cities in the UAE. Investments in zero-waste efforts, geothermal cooling and waste-water recycling will also contribute to the city's zero-emissions target.

Historically, countries have gone about this 'creative destruction' in different ways. Europe in general, and Scandinavia in particular, has put strong emphasis on social and labour market policies, underpinned by the idea that skills and people – not specific jobs in existing industries – should be protected. When jobs are made redundant, policies should be implemented to retrain people in new sectors. It is the quality of social and labour market policies that will determine the extent to which a particular rate of structural change, such as that required for an ambitious climate change policy, will be politically feasible and socially acceptable for China.

In our research, Cai *et al.*[48] reaffirm the importance of implementing active labour policies to soften the negative employment impacts caused by a transition to a low-carbon economy. Cai notes that job losses are likely to occur in certain sectors and regions if the labour market is not responsive enough. Some sectors will be hit especially hard by a shift to a low-carbon economy – coal mining and some heavy industries in particular. However, it is also worth noting that although heavy industry may be the number one energy consumer and polluter in China, it does not do well at creating or absorbing employment. In fact, the present dependence on capital-intensive heavy industry may make it more difficult for China to absorb surplus rural labour.

In a low-carbon transition, sectors such as light industry and services will grow more rapidly, which could make it easier to absorb rural labour. China has good opportunities in the global race for green jobs, supported by its recent economic stimulus packages. For instance, China surpassed the US in the number of new wind turbines built in the first half of 2009. In wind power, local demand often means local jobs, particularly in China, where domestic regulations require that companies must recruit 70 per cent of its employees locally.[49] Green job opportunities in China are likely to increase, and support an overall shift to a knowledge-based and services-oriented economy. Thus, in the long run and with sound government

Box 7: China goes green[50]

China has already made considerable progress in developing low-carbon technologies in a wide range of sectors. Policies and innovation strategies that encourage green innovation and investments are being introduced. Improvement targets are set for many sectors and strata of society, as well as compulsory laws and better city planning.

There are currently over 50 million electric bikes and motorcycles in China, and the array of available low-carbon transportation is being expanded further. China is now leading the mass production of electric hybrid cars. Incentives for energy-saving markets are being created through a number of government policies. Energy efficiency improvements in industries such as metals and cement have helped China to save more than 900 billion kWh over the last four years. In 2008 China generated 12 million kWh of wind power, a figure set to double every year in the upcoming years. Furthermore, the government's energy conservation targets promote the use of low-carbon building materials, and several 'eco-cities' are in advanced stages of planning.

policies in place, employment should not be negatively affected by the transition to a low-carbon economy.

Moreover, such a transition presents a multitude of other opportunities for China that sit well with its development aspirations. By developing service sectors, scientific and technological research and development, and a knowledge-based economy, China can move up the value chain in production of goods and services and capture future comparative advantage. This will bring better-paid jobs, and diversification of its economic strengths will provide for more dynamic and healthy growth. And the earlier that China takes strong action towards a low-carbon economy the greater these opportunities will be. Thus, a future of deep carbon reductions is also a future of significant opportunity for China.

The labour market will however need time to adapt, and the extent of the transformation that China will need to undergo in pursuit of low-carbon development must not be underestimated. This underlines the need for careful implementation of a broad emissions reductions strategy – one that would help to stabilise the economy, enable economic restructuring, and also facilitate structural shifts in the labour market. Our research suggests that, complementing pricing and market policies, a labour market strategy for a smoother adjustment path should include the following elements:

- Active policies to improve the functioning of labour markets and move labour to expanding light industries and services.

- Increased labour mobility across regions within China, where integration of the welfare system across regions may encourage mobility.

- Promotion of education, training and employment opportunities in service sectors and other new sectors created by a carbon-constrained global economy. This must include the expansion of secondary and university education to provide a sustained supply of skilled labour to enable China's transition to a services-based economy.

- Provision of training services to enterprises to facilitate dissemination of energy saving technology and growth of these sectors. Given that skilled human resources are a bottleneck limiting the development of low-carbon industries, the Chinese government could play a more active role in basic research, training, and other public services to support these enterprises. This could help achieve, the necessary balance between emissions reductions and reducing unemployment costs. This is also an important area for international co-operation.

The next two chapters explore key macro-economic policies for enabling deep carbon reductions and offsetting some of the consequential social costs. Nevertheless, further research is required to better grasp the implications of such a full-scale and complex transformation of China's economy. This research could focus on: detailed sectoral-level policies in areas with the highest mitigation potential; regulatory measures to ensure consumers can overcome market barriers and respond efficiently to price signals; and the measures necessary to avoid or offset potential negative social and economic distributive impacts.

4 MARKET MECHANISMS TO PRICE CARBON

Climate change is frequently described as the greatest market failure ever. Current market mechanisms and institutions do not adequately internalise – that is, reflect – and pass on the actual costs of using fossil fuels to producers or consumers. Thus, the first step to correct this market failure must be to internalise the costs associated with greenhouse gas emissions.

Placing a higher price on carbon is at the heart of any strategy to cut emissions and increase energy efficiency. Pricing carbon creates incentives for companies and individuals to produce and consume less carbon-intensive goods and services, and to undertake abatement opportunities to reduce their overall carbon footprint. Furthermore, the higher the price of carbon, the higher the potential gains from the sale of excess emissions rights in an international emissions trading system. Also, anticipation of higher carbon prices sets an incentive to develop low-carbon technology and products, and can thus steer investments in this direction. Economists tend to prefer a global price, which would create a level playing field for all producers.

In practice, however, a price on carbon means more expensive goods and services, which means that implementing it is a major political challenge, even in the current global environment of relatively low energy prices. Levels of income vary between different countries, as do local prices for labour, land and other inputs. Therefore, a global price would cause sharply divergent effects on both consumption levels and the distribution of income in different countries. In particular, a high carbon price could also have a significant impact on the distribution of wealth between different countries (this would also depend on the allocation scheme adopted under a global climate regime, see chapter 1). A measure such as a uniform, across-the-board tax could have unacceptable equity implications. An urban slum-dweller struggling to pay for fuel for daily cooking would be hit substantially harder than those more well-off with secure access to basic goods and services. The same kinds of problem (though on a smaller scale) could also occur on a national level, should countries take autonomous decisions to hike the carbon price. Any price – global or national – on carbon or carbon emissions therefore must be accompanied by actions to soften these negative consequences.

This chapter explores the suitability, effectiveness and implications for China of various carbon pricing instruments. It then explores policy issues that China and the international community should consider when establishing and participating in international emissions trading systems. It also offers suggestions for managing the political reality and economic consequences of carbon pricing and cap-and-trade regimes emerging unevenly throughout the world.

4.1 PHASING OUT SUBSIDIES

To place an accurate price on carbon, an essential first step is to phase out the subsidies on fossil fuels. Such subsidies have many forms, including direct subsidies through low, regulated prices, or tax levels (or depreciation rules) that are lower than on comparable products. These subsidies worsen the existing market failure because consumers are given the incentive to use more fossil fuels. They also counteract efforts to improve energy efficiency and energy security, as producers are given incentives to waste fuel, and reduced incentives to invest in clean energy.

The use of subsidies is common in both developing and developed countries. In 2007, the total amount of subsidies to fossil fuels in the 20 largest developing economies amounted to more than USD300 billion. Eliminating fossil fuel subsidies worldwide would reduce global greenhouse gas emissions by ten per cent in 2050, according to the OECD and IEA.[51] In addition, removing subsidies frees up much-needed resources which can then be directed to climate policies, such as funding adaptation measures and low-carbon technologies. For instance, the UNFCCC estimates that slightly over USD200 billion per year in incremental investment and financial flows would be required to return global emissions to 25 per cent below 2000 levels by 2030.[52]

This issue has been recognised by China and the G20 in a recent communiqué at the Pittsburgh Summit, where China and G20 leaders backed a proposal to phase out and rationalise inefficient fossil fuel subsidies over the medium term, while encouraging targeted support for the poorest.[53] In China's case, although energy subsidies have gradually decreased, allowing prices to converge towards international market prices, further efforts to lower and eventually remove subsidies is an integrated part of the country's overall price reform. Furthermore, although China is making some efforts to rebalance the allocation of capital and lending away from heavy industry, this process of macroeconomic restructuring and financial reform should be continued.

4.2 CARBON TAX

Liberalisation of prices will not alone be sufficient to reach climate targets. Prices on fossil fuels must be raised further, either through taxes or a tradeable permit system. Both mechanisms work to reduce emissions in different ways. Carbon taxes, as an environmental tax on carbon dioxide, act indirectly to reduce demand and thereby emissions, while emissions trading systems limit emissions directly by defining and restricting the available amount of emissions permits.

In our research, Cao[54] indicates that even a fairly small carbon tax would bring substantial emissions reductions in China at only modest cost. A carbon tax regime would bring substantial co-benefits to the macro economy by changing industrial structures and energy sources, improving economic efficiency, and reducing local damage to health and the environment. Revenue from carbon taxes can be recycled to lessen the current distortions within China's fiscal structure, for instance through improving the efficiency of capital and value added taxes, removing highly distortive subsidies on energy prices, and further reforming electricity regulation.

Ideally, the carbon tax should cover all the significant greenhouse gases. Practical difficulties usually arise, however, in levying a charge on methane produced by agriculture and measurements of non-CO_2 greenhouse gases. Therefore, in the initial stages only fossil fuels should be taxed, based on their carbon content. A carbon tax also presupposes a number of administrative and institutional reforms, such as a robust monitoring mechanism for measuring emissions output.

Another challenge lies in finding the right level of tax. An initial national carbon tax should be high enough to significantly affect behaviour, but not so high that it would lead to unacceptable effects on employment that cannot be alleviated by social and labour policies. Cao suggests an initial tax level which will increase the price on coal by 10–20 per cent. However, if a tax is accompanied by other measures to stimulate employment and a shift of labour to other sectors, the carbon tax level may turn out to be higher. In the longer term, the price on carbon must rise much higher,[55] if the deep carbon reduction scenario presented in chapter 3 is to be implemented.

Higher prices on carbon will have distributional effects. China's main political concern over any energy-tax reform is that it will be regressive, so that increases in energy prices may stimulate structural inflation and hurt lower income groups. In fact, even if the government waived the carbon tax for poorer sections of the population, empirical studies suggest that most energy taxes tax or carbon taxes are likely to be regressive, so the poor will be hit even with carbon tax exemption.

In a previous paper, Cao[56] explores the consequences of implementing an environmental tax, in particular, its potential effects in exacerbating pre-existing tax distortions, and thus driving up welfare costs associated with environmental tax reform. In her analysis, she compares the effects of two environmental tax regimes: a direct fuel tax (input tax) on primary fuels, and an indirect tax (output tax) on output products. Cao concludes that an output tax is more likely to exacerbate rural-urban migrations distortions than an input tax. Thus, an input tax on fuel might be preferable over an output environmental tax. The government should consider the option of combining a carbon tax with other measures aiming at balancing these effects, for example by redistributing some of the carbon tax revenues to mitigate the negative social impacts. This may require different types of compensation regimes. The topic merits more detailed study.

In our research, Edenhofer *et al.*[57] demonstrate that, to achieve ambitious climate mitigation targets, environmental taxes should be applied to all sectors, or at least strongly limit tax exemptions, as each tax exemption increases the cost of achieving abatement targets. This is further emphasised by experiences from Germany and Norway (see box 8 and box 9). When the main goal is to reduce CO_2 emissions, it is also important to tax the carbon content of fossil fuel input rather than energy output in order to exploit all cost-efficient abatement options along the supply chain. The efficiency of environmental taxes is weakened by factors such as infrastructure lock-in, which reduce the flexibility to substitute polluting activities/fuel sources with cleaner alternatives. This underscores the importance of supplementing any price mechanism with other policy instruments, like subsidies for research and development (R&D) or efficiency standards, to increase the possibilities for substitution.

Environmental taxes can and should be designed, marketed and implemented to address public and business concerns without jeopardising environmental objectives. For instance, indexing taxes to inflation may ensure their influence over the long-term and at the same time increase their political acceptability. Repeated tax increases may face major political opposition, and therefore create political risk which has to be carried by firms planning long-term investments. On the other hand, taxes that are automatically adjusted to inflation create more stable planning conditions. Also, most

Box 8: Environmental tax experiences in Norway[58]

Beginning in 1991, Norway introduced a hybrid between an energy tax and a resource tax. A carbon tax was put on fossil fuels, while energy taxes were levied on electricity, as well as oil and natural gas used for heating. However, a large share of emissions-intensive industries and other sectors are exempt (coal, pulp and paper, fisheries, cement, metal processing and air transport) and there are differentiations in the tax. This means that many resource-intensive industries have to pay only a small share of the normal tax rate so that, in effect, the tax burden is mostly borne by the consumers. Norway's environmental tax is indexed to inflation.

Since its introduction, Norway's energy and CO_2 taxes have lead to a decrease in CO_2 emissions, although the exact amount of this reduction which can be attributed to tax effects is uncertain. The most visible effect of the Norwegian environmental tax was the early deployment of Carbon Capture and Storage (CCS) technology at the Sleipner gas field in the North Sea by StatoilHydro – the oldest CCS project in operation. To avoid paying carbon taxes levied on venting excess CO_2 into the air, Statoil decided to dispose of carbon dioxide in a deep saline aquifer. Since 1996, Sleipner has been storing about one million tonnes of CO_2 a year.

Box 9: Environmental tax experiences in Germany[59]

In 1999, Germany introduced an end-user eco-tax on electricity, transport fuels, natural gas, and light and heavy oils, repeatedly raising the rates until 2003. The tax generated a total revenue of just under one per cent of national GDP. The revenues from the eco-tax were in the first years exclusively used to reduce employers' and employees' social security contributions. In later years, roughly 10 per cent of the revenues were transferred to the general national budget, while one per cent was used to fund the promotion of renewable energies.

Germany's eco-tax has delivered both economic and environmental benefits. Social security contributions are estimated to be about 10 per cent lower than without energy tax, and fuel consumption has decreased. Fears about reducing companies' competitiveness have not materialised; rather, most companies actually gained from the introduction of the eco-tax.

Criticism of Germany eco-tax generally focuses on three issues: the tax is too limited to have a large impact on the ratio of labour versus growth rates in energy productivity, the tax is inefficient since it sets a price on energy, instead of directly on fossil fuel carbon, and major tax exemptions (e.g. manufacturing industry, agriculture, forestry) strongly reduce the taxes' cost-effectiveness.

energy taxes recycle the revenues to enable reductions of social security contributions or income taxes – the so-called 'double dividend' – thereby leading to a net reduction of tax at the firm level.

Additionally, Ackerman[60] indicates that concerns about losing international competitiveness through implementation of an environmental tax are largely misplaced (see also section 4.5). Other factors like infrastructure, wage levels, education and proximity to growing markets have a higher influence on competitiveness and choice of location than environmental regulation. Furthermore, the ongoing shift towards energy taxes in many countries will lead towards a more level playing field, reducing the competitive pressure on energy-intensive firms as competitors face similar increases in energy prices.

4.3 CAP-AND-TRADE SYSTEM

Another mechanism to price carbon is through an emissions trading regime. Our research by Edenhofer *et al.*[61] shows that emissions trading holds some key advantages to tackling climate change, and building a functioning global cap-and-trade system should be the key mid-term goal of global climate policy. By making pollution rights explicit and transferable, the market is able to value and trade these rights. As a result, emissions reductions can occur wherever they are cheapest. National or regional emission trading systems can also be linked into a global system or regionally interlinked systems of emissions trading, with appropriate burden sharing and harmonised carbon prices. In addition, a global cap-and-trade system also allows for integration into a global carbon market, as discussed further in section 4.5. A national emissions trading system in China would facilitate the long-term goal of international harmonisation of carbon prices.

To set up a cap-and-trade system requires effective administration as well as a mature legal system. Emissions must be measured and monitored, individual emitters identified and charged correctly, and trading of the permits requires a well-functioning market with a high degree of sophistication. Consequently, such a system cannot be built rapidly. China is now creating pilot projects to start trading in small volumes. Within a number of years, this will have the potential to develop into a fully fledged system for emissions rights trading. This is an area where international support and experience, particularly from the European trading system, could help China move more quickly towards a domestic carbon market and eventually to link up with international carbon trading systems.

As China builds a future trading system, a significant concern over its design and implementation centres on how to distribute permits. This step is contentious because it critically determines the policy's distributional impact. Permits can either be sold, usually through auction, or allocated for free. The key question is who receives the revenue created by capping emissions. Our own studies by Brunner *et al.*[62] suggest that free allocation of permits may distort incentives for reducing emissions. There are three main disadvantages of free allocation:

- Firstly, the expectation that the baseline year for allocations will be updated may encourage polluters to invest in dirty technology, or refrain from investing in clean technology, in order to increase or maintain emissions levels and thus receive more free permits in future. Thus, the system may cause unwanted lock-in effects into old technologies.

- Second, free allocation may present a barrier to market entry. If existing polluters receive permits for free, but new plants must pay for them, free allocation reduces competition. At the same time, it may present a barrier to market exit. The requirement that an installation must be kept open in order to receive free permits may prevent the closure of inefficient plants, freezing emissions at higher levels than would otherwise be the case.

- Third, free allocation leads to increased lobbying because emission permits, which have a monetary value, are given out for free. Lobbying of powerful producer groups may put governments under considerable pressure.

Auctioning, on the other hand, offers several advantages over free allocation.

- Firstly, it places upfront costs on polluters. This will tend to enhance management's awareness of carbon cost, leading to more efficient decisions.

- Second, auctioning raises revenues that can be used to address equity issues through reductions in taxes or other distributions to low-income groups. Governments can also use these revenues to invest in the development and deployment of cleaner technologies, or provide finance

Box 10: The 'Green Paradox' does not hold for China

One potential problem of imposing a carbon tax that increases over time is that owners of natural resources have an incentive to extract resources at a faster rate, resulting in short-term increases in resource use and emissions. This is called the 'Green Paradox'.

This paradox makes it difficult to estimate how patterns of resource extraction and resource prices will change in response to an increasing carbon tax. This leads to strategic uncertainties, and complicates the process of achieving optimal negotiated emission trajectories. This is particularly important with respect to oil extraction. Because of the dynamic strategic behaviour of fossil-resource owners, it will hardly be possible to implement taxes that fully internalise the social costs of burning fossil fuels. However, because a quantity cap on emissions imposes a binding upper limit for resource extraction, resource owners cannot extract more than allowed under the cap. This is an additional advantage of cap-and-trade systems in achieving high environmental effectiveness.

However, the 'Green Paradox' argument may not hold for China, since the national government controls all fossil resources. Thus, unlike the global oil market where there are numerous competing producers, there should be no conflict between a higher price on carbon on the one hand, and the short-term interests of competing oil producers to maximise profits on the other.

for other countries' efforts for climate change mitigation and adaptation. This is analogous to the 'double dividend' feature of carbon taxes. Recycled revenues from auctioned permits can have efficiency benefits if they are used to reduce distortive taxes, whereas free allocation of tradeable permits may be regressive because it can transfer income towards higher income groups (i.e. shareholders) at the expense of poorer households (i.e. consumers with high income shares of energy expenditure).

- Third, auctioning provides stronger incentives for technological innovation. Under free allocation, some sources are buyers and others sellers. Sellers have an incentive to behave strategically and keep prices high by avoiding technological innovation. In auction markets, all emitters are buyers. Hence, all sources benefit from low-carbon technologies because of the decreased cost of abatement and lower permit prices.

Overall, auctioning can avoid many of the problems associated with free allocation and offers distinct advantages, although even with the auctioning system, good design is necessary to avoid inefficiencies. Small, frequent auctions may be effective in limiting the market power of large bidders. Such auctions may also encourage learning processes, help players to adjust bids, and promote price stability. In contrast, one large auction at the beginning of each trading period may minimise administrative costs. However, it may also enable large polluters to buy the bulk of permits and use the permits to extract higher payments on the secondary market.

4.4 CHINA'S CHOICES FOR A CARBON PRICING MECHANISM

So should China choose taxes or a cap-and-trade system? Economic theory gives no universal conclusion whether a tax or a cap-and-trade system is better suited for putting a social price on carbon. The uncertainties around the cost of mitigation and the cost of climate damages are significant and difficult to quantify. The previous sections have shown that both systems have pros and cons, and a number of economists recommend a hybrid of the two instruments in the form of a trading system with a price floor and ceiling.

Our conclusion is that a domestic carbon tax is probably the more robust instrument for cutting carbon emissions at this stage of China's development. It also appears to be the favoured option of China's policymakers, as auctioning permits (as under a cap-and-trade system) is a politically sensitive issue in China. It is expected to use free allocation rather than auctioning of permits, such as is occurring in the sulphur trading regime for the electricity sector. China has little experience with trading permits, and it will take time to cut down the transaction costs of a trading regime.

A carbon tax in China is also the more practical option from a policy perspective. Existing institutions will find it easier to implement a carbon tax, it may involve smaller transaction costs, and its use would also align with the broader reform of the resources tax base that is currently under way. A trade mechanism requires more sophisticated systems for monitoring and implementation. In addition, in the event that a carbon tariff is introduced, China might face tremendous pressure to put forward a domestic carbon tax, so that exported commodities can be waived under the current WTO rules.

China could choose to adopt a carbon taxation system in the early stages of its transition to a low-carbon economy, complemented by a cap-and-trade system that could become the more dominant carbon pricing instrument further down the track. Because China would have excess emissions rights to sell to OECD countries, such a strategy could generate export revenues. China could also extend its offsets program to gradually access the global carbon market. This would eventually drive down the transaction costs while building monitoring and reporting capacities for such a trading regime in the future.

Thus, in practice, both carbon pricing systems can co-exist in the immediate future, with a domestic carbon tax existing in parallel with cap-and-trade until such time as China chooses to join an international emissions trading regime. Both instruments, however, need to set a credible long-term carbon price for investors, sensibly re-allocate revenue from auctioning permits, and ensure that there is broad coverage of all greenhouse gas-emitting sectors. Furthermore, both pricing instruments have to be extended by technology support mechanisms to account for market failures in clean technology markets, a subject further addressed in chapter 5.

4.5 A GLOBAL CARBON MARKET

A global carbon market can be established in many ways, either top-down through governments establishing global institutions to cap, trade and monitor emissions, or bottom-up by linking existing efforts to building national or regional emissions trading systems. Clearly, the top-down approach implies considerable challenges for the coordination of international economic policy, and it may be difficult to achieve global consensus on issues such as distribution of permits. Thus, a global carbon market is more likely to emerge step-by-step, for example, by continuing the current approach of the Kyoto Protocol beyond 2012, or by linking national and/or regional emissions trading systems. Similarly, the market should ideally stretch across all sectors and countries. In reality, emissions trading in some sectors and countries will not be feasible due to uncertainties in monitoring emissions, insufficient legal structures and weak property rights.

Our research by Flachsland *et al.*[64] shows that most countries would benefit from engaging in early mitigation and participation in international emissions trading, given that there will be a credible global carbon market in the future. China would benefit from early participation in a global carbon market along with Annex-1 countries, compared to a scenario in which only Annex-1 countries are the first movers in implementing deep carbon reductions. Countries adopting early mitigation targets would be accepting a higher overall reduction burden. However, in most cases, this is more than compensated by the benefits of early action, namely, avoiding stranded investments and greater future mitigation costs, and collecting revenues from the sale of emission permits.

In a transition period, developing countries might adopt trading mechanisms, for instance on the sectoral level. This would have a number of advantages. Countries could begin decarbonising their economic growth, and build the infrastructure required for a more comprehensive future approach. Countries establishing carbon trading mechanisms would gain experience in market-based climate policy instruments. Finally, this may lessen the concerns of industrialised countries over carbon leakage (see section 4.8).

On the government-level, in addition to carbon market instruments, instruments such as taxes, trading or standards need to be implemented, possibly utilising funds fed by international trading to foster low-carbon development.

National or regional carbon markets can address equity issues through creating equitable access to lowest abatement opportunities. They can also address international concerns over the cost of burden sharing and the costs of climate change and emissions abatement by adjusting regional caps and allowing

Box 11: Lessons learnt from the EU cap-and-trade system

The European Union has led the world in regional cap-and-trade systems since introducing its EU emissions trading system (ETS) in 2005. Despite being considered broadly successful, the European ETS has suffered from several problems. Robust emissions data were absent at the beginning of its operation, and the cap was originally set too high, resulting in very low prices. Also, not enough sectors are in the system, and emission rights were not sold but handed out for free. Our review by Brunner *et al.*[63] of the EU ETS experience highlights characteristics that should be included in the design and implementation of a comprehensive and robust future trading system for China. These are listed below.

- The trading system coverage, both in terms of sectors and greenhouse gases, should be as broad as possible in order to maximise market liquidity and the range of potential abatement options.
- Sectors with highly dispersed emission sources (e.g. transport) should be covered upstream in order to keep transaction cost low. Sources which are difficult to measure and monitor (e.g. agriculture) should be excluded from coverage to safeguard the cap's environmental integrity.
- Setting and communicating long-term trajectories for cap and coverage is of paramount importance for enhancing predictability and investor confidence.
- Free allocation of permits can significantly distort incentives, but may ease the introduction of the system in its early stages. Increasing the use of auctioning is likely to generate benefits in terms of cost-effectiveness, distribution, and public finances.
- Monitoring, reporting, and verification of emissions are critical for ensuring a trading system's transparency, integrity, and credibility. Reliable historic data is essential for determining caps at appropriate levels. Stringent verification is essential to correct market distortions, and build trust among investors. Institutions need to be put in place to oversee the carbon market and ensure its effectiveness.

Box 12: A carbon bank

Future permit markets can be distorted by insecure property rights, imperfect information, limited access to markets in the future, or uncertainty about the regulator's future policies. Hence, governments have a key role in managing expectations and supporting the provision of information about long-term abatement options and their costs and risks to all market participants. A carbon bank[65] can assist by stabilising the expectations of firms and regulating the permit market, while guaranteeing the long-term credibility of the carbon budget.

A carbon bank – which could be set up on both the global level and nationally – can manage permits, define trading ratios, monitor transactions, provide banking and borrowing, offer transparent information, and create credibility regarding the fixed amount of permits over time, and hence provide planning security for economic actors. As an independent institution, a carbon bank can reduce regulatory uncertainty about future policies that might be exposed to political pressure (elections or public finance).

for inter-regional carbon credit and permit trade. With national carbon taxes, this would be more difficult to achieve through redirection of international burden sharing funds derived from tax revenues.

4.6 CHINA IN A GLOBAL CARBON MARKET

With international emissions trading regimes emerging worldwide, how can China participate in a future global carbon market? In section 5.2, we introduce a new Chinese proposal called 'Inter-country Joint Mitigation Plans' (ICPs). ICPs would act as an intermediate framework for collaborative mitigation action for the period before the adoption of binding mitigation targets. ICPs aim to cost-effectively realise potential for emissions reductions in developing countries, while ensuring the required financial flows and technology transfer from industrialised countries.

Additionally, Flachsland *et al*.[66] suggest that developing countries such as China have a range of choices about how to participate in a future global carbon market. These options have varying benefits and shortfalls with respect to the policy's environmental effectiveness, distributional considerations, institutional feasibility and co-benefits.

Economy-wide cap

China could adopt economy-wide caps and have the government trade on behalf of the economy. China could still implement domestic policy instruments for reducing emissions, with options including emissions trading for companies, carbon taxes, combinations of these approaches, standards, and R&D support schemes for low-carbon technologies (including subsidies for low-carbon technologies). Moreover, revenues from international emissions trading can be used to implement these domestic instruments, such as via tax cuts.

Adopting a national emissions cap does not necessarily mean that China will be required to reduced emissions. If accepted by industrialised countries, this cap may initially be implemented on a 'no-lose' basis, ensuring that developing countries do not need to buy permits if emissions rise beyond the cap. Nevertheless, there would be an incentive to reduce emissions below the cap via selling emissions. This implies that as long as China's emissions are below the cap, there is an opportunity cost if emissions increase, because permits used for emitting cannot be sold on the international market. Thus, even no-lose trading can provide an incentive.

Absolute sectoral caps – government trading

Instead of setting a cap for the entire economy, China could set caps only for particularly emissions-intensive sectors, and the government could trade internationally on behalf of these sectors. Again, domestic policies are required to translate the signal from the international carbon price for domestic companies.

Setting a series of sectoral caps in major developing countries such as China is one way of implementing an international sectoral cap-and-trade regime that would mitigate concerns over carbon leakage. If a developing country cannot sell a permit due to the expansion of domestic emissions, for example, from the aluminium or steel sector, it suffers an opportunity cost. In fact, addressing carbon leakage in such a manner could enable more ambitious reduction targets in industrialised countries. If sectoral caps are implemented, it is important to ensure that the boundaries of the sector are clearly defined, so that facilities cannot 'leak' out of a sector (e.g. through redefining affected facilities).

Sectoral entity-level cap-and-trade with international linking

China may also implement cap-and-trade systems for certain sectors at the facility-level (e.g. electricity, iron and steel), and enable covered entities to trade permits internationally. Such an approach may also be part of an international sectoral agreement. It would eliminate the need for government trading on behalf of companies. In fact, this approach is identical to the efforts by industrialised countries to link domestic cap-and-trade systems internationally. As with all other approaches discussed in this section, where the cap is set will crucially determine environmental and distributional effects. Also, the covered sectors will directly face the international permit price, and in a competitive market polluters will pass on the costs to consumers wherever possible.

Economy-wide intensity target

An economy-wide intensity-based trading system is characterised by an intensity benchmark for the entire economy, such as in the form of emissions per unit GDP. Credits are generated by taking into account actual GDP and emission levels in relation to the intensity benchmark. As the intensity target is applied to the whole economy, credits are issued to the government. Again, domestic policy instruments are required for this system to succeed.

The major argument in favour of intensity-based systems over absolute targets is that with uncertainty about economic development, there is less risk that a booming economy will exceed the cap (in the case of binding absolute targets, purchasing permits may be necessary). Vice versa, in case of an economic recession, no excess permits become eligible for sale (as would be the case with absolute caps), which may be a concern for some industrialised countries. The major argument against intensity targets is that they do not provide certainty about emissions reductions, as expanding GDP (or another benchmark indicator) enables more emissions. However, intensity targets may be a useful instrument for transition periods, where the major policy objective is to start decreasing emissions growth rates of developing countries.

Sectoral intensity targets

Analogous to absolute caps, intensity targets can also be applied for single sectors instead of the entire economy. The Center for Clean Air Policy (CCAP)[67] has worked out a widely discussed proposal featuring no-lose intensity targets at the sectoral level. In this proposal, developing countries would implement intensity targets for emissions-intensive sectors such as electricity or iron and steel. When actual emission intensities are below the baseline, the corresponding emissions reductions are certified and can be sold on the international carbon market. If emission intensities exceed the baseline, there is no need to purchase permits for developing countries.

For this proposal to be effective, benchmarks need to reflect the technological potential for reducing intensities to ensure that there is an incentive to actually overachieve on the target. Also, benchmarks may reflect the contribution developing countries to emissions mitigation by setting them lower. As long as the intensity of sectoral emissions is below the benchmark, there is a disincentive to operate facilities with high emission intensities.

However, there are a number of additional issues to consider with such a proposal. It introduces an incentive for operating additional facilities with intensities below the baseline, possibly giving rise to concerns over subsidies for leakage. As with all other government-based trading mechanisms, this proposal leaves open the question of which domestic policy instruments to choose. Furthermore, this mechanism fails to incentivise the abatement option of reducing the demand for a sector's products, which may be used more efficiently or substituted by other materials given an appropriate price signal.

Sectoral projects

Sectoral projects operate by implementing some kind of programme or policy (e.g. a technological standard or a tax) and then calculating the amount of induced emissions reductions that determining the amount of credits for sale. In general, both governments and companies could initiate such projects. The major challenge is to calculate the emissions reductions actually induced by any such programme. Also, it needs to be established whether a policy would not have been implemented in absence of the emissions trading mechanism (additionality criterion).

Single projects, bundles of projects

Instead of designing policy instruments for the entire economy or sectors, greenhouse gas abatement may be rewarded on the project level, an approach employed by the current Clean Development Mechanism (CDM). Methodologies for setting baselines and determining additionality need to be developed for each type of emission reduction activity, and transaction costs reduced.

It is also conceivable that several individual projects could be bundled together under one single baseline. This can broaden the scope of single projects, facilitate the process of baseline development, and reduce transaction costs.

4.7 INTERNATIONAL HARMONISATION OF CARBON PRICES

From an economic perspective, if a global carbon pricing policy is to be effective, carbon pricing mechanisms should be implemented in most regions of the world, and pricing needs to relatively uniform. Price harmonisation can enable deeper emissions reductions and ensure efficiency in the worldwide distribution of abatement effort: with appropriate market institutions, investment in emissions reduction should flow to the countries where the costs of reduction are lowest. Again, emission trading systems offer advantages over national carbon taxes in this respect, as international harmonisation of carbon prices is easier with trading systems other than carbon taxes.

However, as noted in the opening of this chapter, a global carbon price can have disproportionately negative effects for developing countries, where incomes and welfare standards are lower. Depending on the level of carbon price and the allocation scheme, a high carbon price could also have a huge impact on the distribution of wealth *between* different countries. For developing countries, carbon emissions, or the credits for avoiding them, will account for a much larger fraction of the value of production. The potential dissonance between expensive carbon and cheaper local inputs, as explored by Ackerman,[68] creates both an obstacle and an opportunity.

The obstacle is that development may be distorted in the direction of activities that yield marketable carbon reductions. Even undesirable activities may be promoted in order to generate carbon credits. In circumstances where governments intend to grandfather permits nationally, and/or need baselines to allocate permits internationally, safeguards are needed to prevent 'carbon-allowance-seeking' investments. Auctioning of permits and/or adopting a resource-sharing approach can assist in avoiding these difficulties.

The opportunity created by this same pattern of prices is that much deeper reductions in carbon emissions will be economical in developing countries. In the simplest terms, saving a tonne of carbon is 'worth' more hours of labour at a lower wage. So there may be a category of carbon-saving investments and technologies that are profitable only in developing countries, where the trade-off between carbon and other inputs is more favorable to emission reduction. With appropriate public initiatives and financing for these technologies, developing countries could 'leapfrog' beyond the patterns of energy use in higher-income countries, establishing a new frontier for carbon reduction. Chapter 5 explores the need for research and development in clean energy technologies, and details the ICP proposal to facilitate technology transfer to developing countries.

4.8 INTERNATIONAL COMPETITIVENESS AND CARBON TARIFF PROPOSALS

One of the obstacles to international action on climate change is the concern that if only some countries introduce a price on carbon emissions they will place their industries at a competitive disadvantage. Other countries with lower carbon prices, or none at all, will have lower costs of production and could win an increased share of world markets. Additionally, some part of the expected reduction in emissions could be lost through 'leakage', as carbon-intensive industries migrate to carbon-tax-free locations.

Carbon tariffs (or border tax adjustments) have been proposed as a measure to eliminate any unfair advantage from low-carbon prices. It is essentially a tariff on the carbon embedded in imports, bringing the price of the embedded carbon up to the importing country's standard. Large-scale emissions leakage can only occur in industries that are both internationally competitive and highly carbon-intensive (i.e. energy-intensive, primary materials industries). Thus, proposals have focused on targeting policies specifically at such industries, where international differences in carbon prices could conceivably cause leakage of carbon emissions to lower-priced regions.

Ackerman[69] concludes that carbon tariffs targeted specifically at such industries would not be of great value for developed countries. At the same time they would do little harm to China. Internationally competitive and highly carbon-intensive industries are few, and account for only a very small fraction of US and European economies. And as China has a comparative advantage in only one such industry (see box 13), carbon tariffs would also have little effect on China's trade. Thus, China does not have to fear a global environment where carbon prices are higher – but neither does it stand to gain significantly.

Consequently, as long as carbon tariffs stay low, they are not a climate tool that would bring a significant distortion to the overall trade flows between China and the rest of the world. Nor would they place internationally competitive, energy intensive industries at a disadvantage. However, there may be a risk that, even if limited to affected industries, such tariffs can trigger retaliatory tariffs and an escalation of protectionist measures in other sectors.

Moreover, there are numerous practical problems with carbon tariffs. They would have to be differentiated by country of origin, since carbon prices could vary around the world. The taxes would also depend on elaborate calculations of embedded carbon: complex manufactured goods often contain components from more than one country, with differing carbon intensities and, perhaps, differing carbon prices. Carbon tariffs thus hardly seem feasible in practice, as they would require a complete life-cycle assessment for each single product that is imported. Neither are they a well-functioning instrument for combating climate change. Still, there is a risk that nationalistic politicians will be tempted to use them for domestic policy reasons.

Box 13: Embedded carbon in China's trade

There are some fears in China that a curb on carbon emissions would hurt China's trade, since China's industrial production is relatively carbon intensive. Ackerman explores this topic[70] and makes several conclusions.

Firstly, China's success in world trade is not closely tied to carbon intensity or cheap carbon; rather it is based on cheap labour. China's position as a net exporter of carbon does not result from exporting uniquely carbon-intensive products. China is of course remarkably successful in world trade. And China also has very carbon-intensive industries. However, these two facts have little to do with each other: China's most successful export sectors are not its most carbon-intensive ones. China's comparative advantage resides in a combination of advanced and traditional manufacturing, with only a minor role for natural resources. China is a net exporter of many manufactured goods, including both high-technology products such as electronics and machinery and traditional manufactures such as leather goods, apparel, and textiles. None of the leading export industries are extraordinarily carbon-intensive. Indeed, other economic sectors, where China does not have a comparative advantage, are on average more carbon-intensive.

Secondly, as China develops, technological change may well eliminate the surplus of embedded carbon in trade, even if China retains a large trade surplus in monetary terms. China uses energy less efficiently, and relies more heavily on coal, than many of the developed countries it trades with. That is, it has higher carbon emissions per dollar of output. As a consequence, exports from China are more carbon-intensive than almost all of the imports into the country. In addition, large fractions of China's carbon emissions occur as a result of demands from international trade: emissions that occur in China are, in many cases, incurred in order to satisfy final demand in other countries. Economic growth, however, is likely to bring more advanced, carbon-efficient technology into use, and may therefore narrow the carbon-intensity gap between exports and imports.

Thus, a vigorous climate policy does not threaten China's trade if the country modernises and shifts towards new technologies. This does not mean that embedded carbon can be ignored in policy debate. Assigning responsibility for exported carbon to the consuming country will provide incentives for high-income importing countries to aid the development process. If the US 'owns' the share of China's carbon emissions embedded in its imports from China, then investing in modernising China will be a much higher priority for the US – and likewise for other developed countries. This will help to promote policies that lead to the joint goals of climate and development.

Furthermore, as noted in the previous section, implementation of international sectoral cap-and-trade regimes is a more effective means of mitigating concerns over carbon leakage than carbon tariffs. In addition to the positive incentives of revenues gained through adopting an international cap-and-trade system, sectoral caps in China could also assist in reducing emissions on targeted industries, as those sectors with expanding emissions would lose out on the economic opportunity to sell excess emissions permits on the international emissions trading market.

5 INNOVATION AND INVESTMENT

Bending the global and Chinese emissions curves to stay below the 2ºC target requires new solutions. The market mechanisms for pricing and trading carbon discussed in the previous chapter are essential to achieving deep carbon emissions reductions in an environmentally effective and cost efficient manner. However, the weaknesses inherent in such market mechanisms mean that other policy and regulatory measures – such as innovation, technology, finance and judicial and administrative reform – must also be used to promote the required shifts in economies, businesses and consumer behaviour.

Innovation is needed in the energy sector, as well as in other climate-related areas such as transport, building, water management, and urban design.[71] Technology, and technology transfer between countries, is critical if we are to break the link between emissions and economic growth. International negotiations on technology transfer negotiations must reach a compromise between protecting intellectual property rights (mostly held in developed countries), and loosening protection of such rights to enable fast technology diffusion (mostly in developing countries). There needs to be a substantial, stable and predictable source of international finance, accompanied by market reform and regulatory mechanisms that can recognise, support and deepen domestic mitigation and adaptation efforts. Industry also needs to upgrade skills in a variety of areas, ranging from workers to management.

5.1 TECHNOLOGY AND DOMESTIC INNOVATION POLICY

Although most of the technologies for a deep carbon reduction path are technically available, they must also become commercially feasible. However, market failures are causing underinvestment and inertia in technological innovation. This is largely due to the prolonged research and development periods prior to commercialisation of technology, and capital-intensive start-up phases. Moreover, if there is no early investment, cost reductions will not happen, making cheap, large-scale abatement in the future very unlikely. China therefore must encourage domestic innovation in, and widespread diffusion of, decarbonisation technologies. At the same time, international efforts are needed to accelerate technology innovation and transfer, and share experiences in fostering governance capacity.

Our research by Fan *et al.*[72] highlights the technological demands set by China to shift to a low-carbon economy. To cope with climate change, Premier Wen Jiabao has made five proposals, and among them he states that climate change must be tackled in part through technological progress. According to China's White Paper,[73] *China's Policies and Actions for Addressing Climate Change*, the country will focus R&D on development of:

- technologies that save energy and enhance its efficiency;
- technologies for renewable energy and new energy;
- technologies that can control, dispose of or utilise greenhouse gases, such as carbon dioxide and methane in industries;
- biological and engineering carbon fixation technology;
- technologies for the clean and efficient exploitation and utilisation of coal, petroleum and natural gas;
- technologies for manufacturing advanced equipment for coal- and nuclear-generated power;
- technologies for capturing, utilising and storing carbon dioxide; and,
- technologies that control greenhouse gas emissions in agriculture and how land is used.

At the top of this list is energy efficiency in both energy supply and end use, particularly in industries, transportations and building. Renewable energy technologies are prioritised, including lower cost wind power and low-wind speed turbines, photovoltaic building materials and large-scale solar systems, advanced bio-refineries and cellulosic biofuels, water photolysis and energy storage options. Recovery and utilisation of greenhouse gases come as number three on the list.

However, despite China's advances in domestic technological innovation, our research by Yang *et al.*[74] indicates that there is further scope to improve its framework conditions for innovation. Some of the measures include increased public investment in research and development of low-carbon technologies, support for demonstration projects, tax and other incentives for R&D partnerships, measures to promote competition and innovation, and phasing out subsidies to established energy technologies, and establishing institutional mechanisms to facilitate and coordinate efficient public investment.

A fully-fledged domestic innovation environment and policy for low-carbon technology would maximise opportunities available through international technology transfers, and will also harbour other spin-off benefits. Some of these are opportunities to rapidly advance through or bypass stages of technological development, assist macro-economic shifts to a knowledge-based economy, and create new industries and job opportunities in sectors such as renewable energy, environmental technology and energy efficiency. For instance, a recently completed study by the China Greentech Initiative estimates that China could build a green-tech market worth USD one trillion per year.[75]

Our research by Edenhofer *et al*.[76] notes that the gains from innovation will not only be limited to improving energy and carbon intensity, but will also continue to drive improvements in labour productivity in different sectors. Hence, technological change influences both the speed of growth and the direction of growth.

Recent studies suggest that technological innovation is not only of key importance for reducing the overall costs of climate change mitigation, but also for making the regional distribution of mitigation costs less dependent on the allocation of emission permits. The larger the technological innovation, and the higher the institutional flexibilities for achieving the overall mitigation target, the lower is the global carbon price. Thus, international cooperation and innovation will reduce the financial flows associated with carbon trade and also help to take the pressure off the negotiations on the distribution of emission rights under a global cap-and-trade framework.[77]

5.2 A NEW PLAN TO BOOST TECHNOLOGY TRANSFER

The domestic innovation environment can be enhanced by international technology transfer. Today, the primary international institution for facilitating technology transfer is the Clean Development Mechanism (CDM) under the Kyoto Protocol. There are well-known problems with today's CDM system. It is cumbersome and slow, not least because it is difficult to ascertain that the projects really add 'additional' mitigation. Furthermore, country receiving assistance under the CDM does not have a cap on emissions, CDM projects may actually increase total emissions. Our own analysis[78] of the CDM experience in China reveals several other limitations of the current system.

- The Chinese CDM shows a weak link between technology transfer practice and the technology demands identified at the national level. Institutionally, the CDM is not linked to the country's national strategy or targets and therefore the CDM is of little benefit to China's national emission reduction actions.

- In the present CDM market, there is little incentive to transfer technology on the side of buyers of emissions rights, and low interest in technology transfer from project owners.

- The insufficient technology transfer in CDM practice reflects major institutional gaps in promoting technology transfer. The CDM does not have a technology transfer mandate, nor is it a criterion for the Executive Board when approving or registering a CDM project. Furthermore, there are no specific proposals or mechanisms for promoting the transfer of environmentally sound technologies.

On top of these problems, the financial benefits of the CDM are minor compared to the investment needs in China. In other words, while China is significant for the CDM, the CDM is insignificant for China. With the inadequacy of CDM practice and the urgency and scale of action required to tackle climate change, new mechanisms will have to play a dominant role in bringing up the level and scale of coverage and operation. In the case of China, it would be beneficial to design a new mechanism that can better respond to its national development strategies and be better connected to mainstream governance structures.

Inter-Country Joint Mitigation Plans

In this context, Fan *et al*.[79] propose the establishment of 'Inter-country Joint Mitigation Plans' (ICP). The ICP serves the same goal identified for the CDM but aims at large-scale emissions reductions – not only project-based or sector-wide, but economy-wide. This puts the sustainable development interests of developing countries centre stage. The ICP is not a new mechanism *per se*, but rather brings together components from a range of existing proposals. The central idea underpinning the ICP is to broaden the channels and extent of international cooperation. Furthermore, ICPs could serve as an intermediate framework in the near-term until binding targets are assumed. Their main strength is that they ensure technology transfer and finance from industrialised countries.

Such a joint plan is formed on the basis of cooperation between a host country (developing country) where the emission reduction takes place and one or more partner countries (developed countries) who share the necessary technology and finance and also the reduction credits. An ICP begins when a host country prepares a national emission reduction plan with voluntary quantified targets, which could be aimed at specific sectors or projects, or even the construction of infrastructure. For example, in China this could mean building smarter electricity grids or developing infrastructure for electrical vehicles. Partner countries review the proposal for joint implementation of the ICP, and an agreement is signed by the governments of all participating countries.

An ICP not only establishes emission targets, but also specifies the technology and investment required to meet the targets. Therefore, the results of the ICP – emissions reduction, technology transfer and financing – must be measured, reported and verified. Furthermore, the technology transfers should also obey the international rules on intellectual property rights.

An ICP ensure that the partner countries gain the low-cost emission reduction in the host country – just as with the CDM, but on a larger scale. ICPs also hold significant commercial opportunities for partner countries and companies because they access the market of mitigation technologies in developing countries. Partner countries can also gain long-term leverage on CO_2 emissions with joint research projects to build new technology demonstration programmes. An ICP with China would be attractive to countries or companies that hold technologies on China's mitigation technology list.

ICPs also provide strong incentives for the host country. The long-term benefits are defined and covered, because an ICP starts with a proposal made by the host country, putting its national interests in the centre and drawing the emission reduction targets from the national sustainable development targets. The host country of an ICP can also leverage foreign investments linked with technology transfers to meet the emission targets and upgrade targeted sectors. In this sense, the ICP has a long-term impact on the sustainable development of the host country, phasing out polluting technologies and phasing in the new ones, avoiding lock-in effects and supporting the structural change toward low-carbon. Furthermore, as developing countries accumulate technological capacity and corresponding knowledge, it will help them to reduce future mitigation costs, so China and the other developing countries would participate in compulsory mitigation earlier. This effect would go some way to help achieve the global emission target.

With the existing interests of the host country and the partner countries as the starting point, and consensus reached through negotiations, ICPs are likely to become a self-enforcing. However, managing an ICP is much more complex than running a CDM project. To operate an ICP, two other necessary conditions are needed: the first is the existence of adequate institutional capacity to manage an ICP (particularly at the national level in host countries, and at the international level through an institution established to assess the ICP proposals, support and coordinate negotiation, and supervise and assess the ICP implementation). The second is the existence of an international fund, which needs to be set up and operated by a multilateral agency to support the ICP process.

While the ICP proposal addresses a number of the CDM's shortcomings (especially with regard to technology transfer and upscaling) other limitations remain. Similar to the CDM, it will be very difficult to quantify emissions reductions against a counter-factual baseline and to ensure 'additionality' of emissions reductions (i.e. that the emissions reductions achieved by the project are genuine and that the project would not have occurred anyway). Further research is needed on detailed implementation of ICPs, to address issues such as: who will receive the revenues for 'low-hanging fruit' – for example, abatement potential that is very cheap compared to the global price of CO_2? Will that rent be taxed, thus generating revenue for the government? Or will only the partner country pay the actual costs? In the latter case, how will projects be managed to avoid one industrialised country taking low-cost projects while others are left with more costly abatement projects?

5.3 INVESTMENT AND FINANCING

Domestic policies and measures in China have been, and are likely to continue to be, the dominant drivers of activity and finance for emissions reductions – a point that is illustrated by China's renewable energy policies. For the world to achieve a low-carbon future, a significant fraction of mitigation investment will need to occur in China. According to Lazarus *et al*.[80] this will amount to 20–40 per cent of incremental investment by 2030.[81] In fact, the more ambitious the emission reduction goal, the greater the share of investment that China must receive. As such, mechanisms to recognise, support, and deepen domestic policies – as implied by the Bali Action Plan – will be central to future international climate agreements.

Estimates of the scale of investment needs in China vary widely (see table 1) and should be treated with caution due to uncertainty over future economic drivers, the pace of change, and technology costs and availability. At the global level, it is estimated that USD200 billion to 1000 billion will be required over the next two decades, and for China, from USD35 billion to 250 billion (the lower figures are UNFCCC estimates, the high ones McKinsey's).[82] Much of this anticipated investment is for emerging technologies such as electric vehicles, or carbon capture and storage – for which there is limited domestic and international support today. Our deep carbon reduction scenario (see chapter 3) does not quantify investment costs, but preliminary analysis indicates that the high ambitions of our scenario will push costs closer to the McKinsey estimates than those of the UNFCCC. This is an important area of further research.

The numbers reported above may make the reader balk: the size of the required investment is indeed tremendous. However, a significant amount of reductions can be achieved with positive economic returns or with only slight to moderate costs (although with high initial investment) once the savings from lower energy use and other efficiencies are taken into account. In China, energy efficiency in buildings and appliances and recovery of industrial waste present such opportunities. Investment needs can also be partly financed from utilising revenues gained from auctioning permits in a cap-and-trade system, levying carbon taxes, or removing subsidies on fossil fuels.

Moreover, these estimates do not include benefits to other public policy goals, such as energy security, air quality, cost savings, and increased competitiveness. Climate change investments will yield social, environmental and financial returns – a cleaner, more modern, energy-efficient and healthier society, as well more rapid development of labour-intensive service sectors. Furthermore, they will reduce the risks of climate change-induced natural disasters, for which the socio-economic costs will likely exceed any mitigation efforts. In the longer run, the true costs of climate change are likely to be much higher than the amount of investment now required to tackle it.

Public domestic finance has been, and will continue to be, an important source in the early stages of transition to a low-carbon economy. In China for instance, state-owned utilities have directly financed much of the investment in renewable energy, providing equity and raising debt – often as high as 80 per cent of total finance – largely from state-owned banks. To the extent that domestic capital is abundant and domestic renewable energy policies themselves are the principal driver for investment, as has been the case in China, favouring domestic investment may not pose a constraint on overall renewable energy investment, at least for commercial renewable energy technologies.

Private financing and the carbon market will play an increasingly important role in meeting China's investment needs. For instance, the successful Initial Public Offering (IPO) of Chinese solar company Suntech at the end of 2005 sparked investor interest. Since then, a steady stream of solar IPOs has followed, with many more in the pipeline. Overall, there is still relatively little private venture capital in China, though the China Environment Fund and others are actively seeking to scale up 'clean tech' investment.

However, to upscale green technologies such as wind and biomass capacity more substantially may ultimately require a greater diversity in financing instruments and international support. International bilateral and multilateral funds have helped to increase the uptake of renewable energy and energy efficiency and build capacity in China and other developing countries. But to meet ambitious climate targets, far greater efforts will be needed in the future.

China's investment needs are predominantly in the power generation sector over the next decade, in carbon capture and storage from 2020 onwards, and in the transportation sector (e.g. electric vehicles) in the longer run. Our research suggests the type of financing mechanisms best-suited to China's needs are as follows:

- A combination of domestic policies and international funds providing debt finance, capacity building grants, and access to advanced technologies. These could be driven towards low-cost and cost-effective options in energy efficiency for vehicles, industry and construction as well as waste management and urban design. International funds can play an important role in guaranteeing private capital for small-scale activities, and financing early stage technologies. Funds (e.g. Nationally Appropriate Mitigation Action Plans) and technology agreements can

Table 1: Annual emissions reductions and investment needs: UNFCCC Mitigation Scenario (in 2030) and McKinsey Abatement Scenario (average 2026-30 for global estimates, 2010–30 for China estimates)[83]

	UNFCCC					McKinsey			
	GHG Emissions reductions [Gt CO_2 eq]		Investment and financial flows [USD billion]			GHG Emissions reductions [Gt CO_2 eq]		Incremental Investment [USD billion]	
Sectors	**Global**	**Non-Annex I**	**Global**	**Non-Annex I**	**China**	**Global**[c]	**China**	**Global**	**China**
Mitigation Investment									
Power generation, of which	9.4	5.0	$149	$73	$36	14.4/10	2.8	$185	$60
Renewables, hydro, nuclear[a]			$85	$47	$19				
CCS			$63	$27	$17				
Industry, of which	3.8	2.3	$36	$19	$12	5.0/7.3	1.6	$140	$20
Energy-related			$20	$7	$3				
CCS			$14	$11	$9				
Other			$2	$1	$0				
Transport, of which	2.1	0.9	$88	$36	$11	3.2	0.6	$375	$90
Efficiency (incl hybrids)			$79	$32	$11				
Biofuels			$9	$4	$1				
Buildings (and appliances)	0.6	0.3	$51	$14	$4	1.3/3.5	1.1	$250	$60
Waste	0.7	0.5	$0.9	$0.6	$0.1	1.5		$10	
Agriculture	2.7	0.4	$35	$13	$4	4.6	0.6	$0	
Forestry	12.5	12.4	$21	$21		7.8		$55	
Technology R&D			$45						
Other									
Total Mitigation Investment			$425	$176	$68				
Avoided Fossil Fuel and Energy Infrastructure Investment									
Transmission and Distribution[b]			-$101	-$48	-$18				
Fossil Fuel Generation			-$55	-$31	-$11				
Fossil Fuel Supply			-$59	-$32	-$3				
Investment Savings			-$215	-$111	-$32			Included in figures above	
Net Mitigation	31.7	21.7	$210	$65	$36	37.9	6.7	$1,000	$190-250

a Combined additional investment needed in renewables, nuclear and hydropower;
b Does not consider increased transmission and distribution needed to provide electricity access to unserved populations in developing countries.
c Where two numbers are shown for emissions reductions, the first number assigns all electricity emission reduction to the power generation sector (similar to UNFCCC), while the second allocates emissions reductions due to decreased electricity demand to industry and buildings sectors.

support acceleration or deepening of efficiency targets and standards, and the commercialisation of more costly and innovative energy efficiency technologies such as hybrid vehicles or smart grid devices (advanced meters).

- Mitigation opportunities where the abatement costs are expected to be in the range of anticipated carbon prices – such as many renewable electricity technologies, biofuels, some advanced efficiency technologies – represent the 'sweet spot' for carbon finance. Sectoral target approaches can support renewable energy standards or incentives, low-carbon fuel standards, or product-based emissions intensity goals. For industrial sectors that are amenable to sectoral approaches due to high emissions intensity and homogeneous products (steel, cement, aluminium), sectoral 'no-lose' targets could support both low-cost abatement options (through policies and measures) and higher cost technologies (through carbon finance). Project approaches, such as project-based CDM, can be enhanced through lists to target technologies and fuels that exceed common practice or high performance threshold.

- Where the marginal abatement costs are significantly higher than carbon prices in the near term, international grant-based funds could support R&D to bring down costs and to support demonstration and deployment, such as in CCS, electric and other vehicle technologies, and higher cost renewable energy technologies.

There are a large number of proposals on international climate financing that attempt to bridge the shortfall between current investment and projected needs. Several of these reflect more innovative mechanisms to raise carbon finance and leverage private-public partnerships. They include recycling revenue from global carbon taxes; investing a portion of developing countries' foreign exchange reserves into mitigation and adaptation; modifying conditions for currency provision (e.g. through donating Special Drawing Rights, or debt-for-clean energy programmes); and using public money to partially guarantee green investments in developing countries.[84] Ultimately, an integrated approach or an international coordinating body will be essential to ensure that a mix of carbon market and fund-based mechanisms will function together in an efficient and adequate manner.

Box 14: Chinese capital seeking productive investment opportunities

China's relative position in the world is changing rapidly, and this will have implications for the issues analyzed in this chapter.

China continues to build its financial strength through the accumulation of the largest foreign exchange reserves in the world; massive savings from domestic banks savings; the profitability of the largest Chinese companies; the growing clout of Chinese institutional investors such as the Sovereign Wealth Funds, banks, insurance companies, private equity funds; and through large state-owned companies like China Energy Conservation Investment Corporation. Some of these funds could be used to nurture profitable green investment: there will be more and more green business opportunities in the areas of renewable energy, environmental technology, energy efficiency, sustainable transport and vehicles, tourism, and agriculture.

As noted by Stern[85] in our research, taking strong action now will create exciting new opportunities for growth and jobs. The next long upswing can be driven by the transformation to fossil-free technologies. Young and dynamic firms investing in future growth sectors and new technologies will create a sustainable job base for the future. Low carbon investments in particular can be pro-growth and pro-job creation. Energy savings can also create the space for financial savings, enabling consumers to afford other goods and services, boosting demand. And China, by investing early in this new growth, gives itself a greater competitive edge internationally.

Implementing innovative policies for private-public partnerships could attract more foreign capital and technology into China to accelerate a transition to a low-carbon economy. For instance, China could give preferential treatment to foreign participants who provide either technology or capital. It could also allow first-mover foreign investors a guaranteed rate of return in order to give these investors comfort and predictability, and to encourage the transfer of technology, know-how and expertise.

6 A LOW-CARBON CHINA IS A MODERN CHINA

The transition to a low-carbon economy will require huge investment, but this investment will also provide benefits. To name only a few, China would be more energy efficient as well as more energy secure, the air would breathable for millions of people with respiratory problems caused by carbon-fired power plants and heating, and transportation would be safer and cleaner.

In this sense, China's transition to a low-carbon economy is an integrated part of the modernisation of China. In our view, the way towards a harmonious society goes hand-in-hand with the low-carbon strategy outlined in this report.

China's rapid growth over the past three decades has been immensely successful in that it has lifted more people out of poverty than at any time in man's history. Hundreds of millions of Chinese have risen to a level of security and prosperity that nobody thought would be possible only a couple of decades ago. But this growth strategy now needs to be renewed, for the following reasons:

- It has been based on cheap coal, creating environmental degradation on a grand scale. The health of the population and access to fresh water and unpolluted land now necessitate a move away from coal as the primary energy source of China.

- The rapid rise of manufacturing has made China the shop floor of the world. However, this development path is now closed. China cannot rely on rapidly rising exports as the main driver of growth, now that it is the world's largest exporter and the second largest economy in the world, in purchasing power parity terms.

- In China, the manufacturing sector has a much larger share of GDP – about 10 per cent higher than in comparable countries. This creates environmental problems and makes job creation more difficult. In the future, growth must be built to a much larger extent on consumption and an expanding service sector.

- As urbanisation continues and millions of rural people move to the cities, a service-based economy will make it easier to create jobs. The service and consumption sectors are more labour-intensive, whereas the old heavy manufacturing sectors are not only bigger polluters but also more capital-intensive.

- The global imbalances which contributed to the recent financial crisis – huge American deficits financed by borrowing from China and its surpluses – must be amended. That can only be done by America increasing its savings and reducing its imports, while China shifts towards a less export-dependent growth strategy.

- In the longer term, the Chinese capital markets need to be modernised. To a large extent this means that old habits of furnishing capital-intensive manufacturing with cheap credit must be abandoned, and that the consumption and service sectors must be able to compete for capital on equal terms.

All of the above point in the same direction. China's modernisation fits hand-in-glove with the 'greening' of China. The necessary investments in new low-carbon energy sources, R&D and education, services, a new transport infrastructure and forestation all contribute to creating a modern, harmonious China. Furthermore, such investment will make China more competitive at the global level as it takes the lead in new low-carbon products and sectors.

The innovative, entrepreneurial and pragmatic approach which has permeated China since the launch of the reform era in 1978 will serve the country well in its endeavours to become a low-carbon economy. Technology, pragmatism and financial resources of various forms will be the catalysts that catapult China into a leading position.

China's quest to become a strong and responsible member of the global economy through accelerated modernisation will allow it to emerge as a global leader in the transformation towards a low-carbon economy. Looking at China's industrial evolution over the past thirty years, it has more often than not been the case that, once the direction has been set, China has managed to make rapid leaps in various sectors of the economy (e.g. the telecom/IT/internet and the automobile industries). In both these sectors China is now the world leader, both in terms of absolute size as well as in terms of technological development.

We hope and trust that China's next five-year plan will be a 'green' plan, reflecting not only a more modern growth strategy to create jobs and increase prosperity, but also a plan for a low-carbon China, which takes a leading role in the global fight against climate change.

The world needs global leadership. China can contribute to this, acting as a role model for many developing countries. And by investing in China's climate action, the world can share in the dividends of a more climate secure future.

REFERENCES

Background papers

Ackerman, F. (2009a) *Carbon Embedded in China's Trade*, (draft report) Boston: Stockholm Environment Institute.

Ackerman, F. (2009b) Policy Implications of Carbon Pricing for China's Trade, Stockholm Environment Institute.

Brunner, S., Flachsland, C., Luderer, G. and Edenhofer, O. (2009) *Domestic Emissions Trading Systems*, Potsdam Institute for Climate Impact Research (PIK).

Cai, F., Du, Y. and Wang, M. (2009) *Emission Reduction and its Impact on Employment: Trade-offs, Scenarios and Policy Options*.

Cao, J. (2009) *Carbon Tax as an Instrument of Carbon Reduction*, Tsinghua University.

Edenhofer, O., Pietzcker, R., Kalkuhl, M. and Kriegler, E. (2009) *Taxation Instruments for Reducing Greenhouse Gas Emissions, and Comparison with Quantity Instruments*, Potsdam Institute for Climate Impact Research (PIK).

Fan, G., Cao, J. and Su, M. (2009) *Fair Emissions: Modified Greenhouse Development Rights (GDRs) and Mitigation Targets*, Tsinghua University.

Fan, G., Han, G. and Li, L. (2009) *Meeting Global Targets through International Cooperation - the Inter-country Joint Mitigation Plan (ICP).*

Flachsland, C., Luderer, G., Steckel, J., Knopf, B. and Edenhofer, O. (2009) *International Emissions Trading and the Global Deal*, Potsdam Institute for Climate Impact Research (PIK).

Heaps, C. (2009) *A Deep Carbon Reduction Scenario for China*, in: *China Economics of Climate Change Initiative*: Stockholm Environment Institute.

Kartha, S. (2008) Comparison of Equity Frameworks and a China Analysis of the Greenhouse Development Rights Concept, unpublished draft report, Stockholm Environment Institute.

Lazarus, M. and Polycarp, C. (2009) International Mechanisms for Greenhouse Gas Mitigation, Finance and Investment, Stockholm Environment Institute.

Stanton, E. A. (2009) Greenhouse Gases and Human Well-Being: China in a Global Perspective, unpublished draft report, Stockholm Environment Institute.

Stern, N. and Bohannon, M. (2009) The Economics of Climate Change (SEI/CE50) - overview of key issues.

Yang, H. and Xing, W. (2009) China's Mitigation Strategies, Policies and Institutions, Tsinghua University.

Other references

Ackerman, F. (2009) *Can We Afford the Future? The Economics of a Warming World*, London: Zed Books.

Agarwal, A. and Narain, S. (1991) *Global Warming in an Unequal World: A Case of Environmental Colonialism*, New Delhi: Centre for Science and Environment.

AOSIS (2009, June 11) *Aggregate Annex-l reductions for 2020,* in: *Compilation and Analysis presented by the Alliance of Small Island States to the Ad Hoc Working Group on Further Commitments for Annex 1 Parties under the Kyoto Protocol*.

Baer, P., Athanasiou, T., Kartha, S. and Kemp-Benedict, E. (2008) *The Greenhouse Development Rights Framework - The right to development in a climate constrained world*, in: *Publication Series on Ecology*, Berlin: Heinrich Böll Foundation, Christian Aid, EcoEquity and the Stockholm Environment Institute.

Barrett, J., Wiedmann, T., Paul, A., Owen, A. and Scott, K. (2009) *Evaluating Sweden's emissions: at home and abroad*, Stockholm Environment Institute.

Cao, J. (2008) *A Dynamic Computable General Equilibrium Analysis of Environmental Taxation and "rural-urban" Migration Distortions in China*, Singapore: Economy and Environment Program for Southeast Asia (EEPSEA).

Center for Clean Air Policy-Europe, The Centre for European Policy Studies (CEPS), Climate Change Capital (CCC), The Centre for European Economic Research (ZEW), and The Institute for Sustainable Development and International Relations (IDDRI)

(2008) *Sectoral Approaches: A Pathway to Nationally Appropriate Mitigation Actions*, In: *Center for Clean Air Policy Interim Report*, Washington DC.

China Greentech Initiative (2009) *The China Greentech Report 2009*, Mango Strategy.

ChinaGate (2009, February 27) Rizhao xunhuan jingji tuidong GDP "lüshe" zhenzhang (Rizhao's circular economy promotes "green" GDP growth) Retrieved September 22, 2009, from http://cn.chinagate.cn/chinese/jj/56465.htm.

Economist (2009a, October 1) Fossilised policy, *The Economist*.

Economist (2009b, September 17) Investors and climate change: Green backing, *The Economist*.

Economy, E. C. (2007, September/October) The Great Leap Backward? *Foreign Affairs*, from http://www.foreignaffairs.com/articles/62827/elizabeth-c-economy/the-great-leap-backward.

Financial Times (2009, November 10) IEA warns carbon price must double, retrieved November 13, 2009, from http://www.ft.com/cms/s/0/ab9e8ffc-ce2f-11de-a1ea-00144feabdc0,dwp_uuid=d68cb1fc-a38d-11de-a435-00144feabdc0.html.

Ford, P. (2009 August 16) The World's First Carbon Positive City Will Be...in China? *ABC News International*, retrieved November 16, 2009, from http://abcnews.go.com/International/JustOneThing/story?id=8327868andpage=1.

Gapminder (Producer) (2008, October 23, 2009) Gapminder World, retrieved from http://graphs.gapminder.org/world.

Garnaut, R., Jotzo, F. and Howes, S. (2008) China's rapid emissions growth and global climate change policy, in L. Song and W. T. Woo (Eds.), *China's Dilemma*, Washington: Brookings Institution Press.

GCI (The Global Commons Institute) (2008) *The Carbon Countdown - The Campaign for Contraction and Convergence*, London: Global Commons Institute.

Hallding, K., Han, G. and Olsson, M. (2009a) *A Balancing Act: China's Role in Climate Change*, [the Commission on Sustainable Development (Ed.) Stockholm.

Hallding, K., Han, G. and Olsson, M. (2009b) China's Climate- and Energy-securities Dilemma: Shaping a New Path of Economic Growth, *Journal of Current Chinese Affairs, 38*(3), 119-134.

HSBC (2009) Wind turbine blades - a sizeable production, Baoding, China, retrieved November 16, 2009, from http://www.hsbc.com/1/2/sustainability/case-studies/wind-turbine-china.

International Energy Agency (2007) *World Energy Outlook 2007: China and India Insights*, Paris: OECD/IEA.

International Energy Agency (IEA) (2008) *World Energy Outlook 2008*, Paris: OECD/IEA.

International Monetary Fund (2009) *World Economic Outlook Database*.

IPCC (2001) *Climate Change 2001: Mitigation*, In: *A Report of Working Group III of the Intergovernmental Panel on Climate Change*.

IPCC (2007a) *Policies, Instruments and Co-operative Arrangements*, in: *Climate Change 2007: Mitigation, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O. R. Davidson, P. R. Bosch, R. Dave and L. A. Meyer (Eds.)], Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

IPCC (2007b) *Technical Summary*, in: *Climate Change 2007: the Physical Science Basis - Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller (Eds.)], Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Jiang, K. (2008) *Energy and Emission Scenario up to 2050 for China*, paper presented at the International Forum on Policy Options for Climate Change.

Lans, K. (2008, February 12) Abu Dhabi bygger koldioxidfri stad (Abu Dhabi constructs carbon free city) *DI*, retrieved October 19, 2009, from http://di.se/Nyheter/?page=/Artiklar/Abu_Dhabi_bygger_koldioxidfri_stad.aspx%3FArticleID%3D2008%255C02%255C11%255C269803%26words%3D%26SectionID%3DEttan%26menusection%3DStartsidan%3BHuvudnyheter

Luderer, G., Bosetti, V., Steckel, J., Waisman, H., Bauer, N., Decian, E., Leimbach, M., Sassi, O. and Tavoni, M. (2009) *The Economics of Decarbonization - Results from the RECIPE model comparison*, RECIPE Working Paper.

Lüken, M., Bauer, N., Knopf, B., Leimbach, M., Luderer, G. and Edenhofer, O. (2009) *The Role of Technological Flexibility for the Distributive Impacts of Climate Change Mitigation Policy*, paper presented at the International Energy Workshop.

Masdar City (2009) Masdar City, retrieved October 19, 2009, from http://www.masdarcity.ae/en/index.aspx.

McKinsey and Company (2009a) *China's Green Revolution: Prioritizing Technologies to Achieve Energy and Environmental Sustainability*, Beijing: McKinsey and Company.

McKinsey and Company (2009b) *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve*, Global: McKinsey and Company.

Meinshausen, M., Meinshausen, N., Hare, W., Raper, S., Frieler, K., Knutti, R., Frame, D. and Allen, N. (2009) Greenhouse-gas emission targets for limiting global warming to 2 °C, *Nature, 458*, 1158-1162.

Ministry of the Environment, and Ministry of Enterprise, Energy and Communications (2009) *Towards an eco-efficient economy - 12 Swedish examples*.

Reuters (2009, September 25) G20 agrees to phase out fuel subsidies, retrieved November 16, 2009, from http://www.reuters.com/article/GCA-GreenBusiness/idUSTRE58O18U20090926.

Rockström, J., Steffen, W., Noone, K., Persson, A., Chapin, F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P. and Foley, J. A. (2009) Planetary Boundaries: Exploring the Safe Operating Space for Humanity, Ecology and Society.

Scott, K. (2009) *A Literature Review on Sustainable Lifestyles and Recommendations for Further Research*, Stockholm: Stockholm Environment Institute.

State Council Information Office (2008, 29 Oct. 2008) White paper: China's policies and actions on climate change, retrieved 29 Oct, 2008, from http://www.china.org.cn/government/news/2008-10/29/content_16681689.htm

The Climate Group (2009) *China's Clean Revolution II: Opportunities for a Low-carbon Future,* Beijing: True North.

US Department of State (2009) The Pittsburgh Summit: Acting on our Global Energy and Climate Change Challenges, retrieved October 20, 2009, from http://www.pittsburghsummit.gov/resources/129661.htm.

UN News Centre (2009, September 22) Secretary-General Ban Ki-moon General Assembly, retrieved November 17, 2009, from http://www.un.org/apps/news/infocus/sgspeeches/statments_full.asp?statID=582.

UNFCCC (United Nations Framework Convention on Climate Change) (2007) *Investment and Financial Flows to Address Climate Change*.

UNFCCC Secretariat (2009, June 12) *Compilation of information relating to possible quantified emission limitation and reduction objectives as submitted by Parties.*

Wagner, F. and Amann, M. (2009) *Greenhouse Gas: Air Pollution Interactions and Synergies Gains - Analysis of the Proposals for GHG reductions in 2020 made by UNFCCC Annex I Countries*, Laxenburg: IIASA.

Wiedmann, T., Wood, R., Lenzen, M., Minx, J., Guan, D. and Barrett, J. (2008) *Development of an Embedded Carbon Emissions Indicator – Producing a Time Series of Input-Output Tables and Embedded Carbon Dioxide Emissions for the UK by Using a MRIO Data Optimisation System*, in: *Report to the UK Department for Environment, Food and Rural Affairs by Stockholm Environment Institute at the University of York and Centre for Integrated Sustainability Analysis at the University of Sydney*, London, UK: Defra.

World Bank (2009) *Overview: Changing the Climate for Development*, in: *World Development Report 2010*.

APPENDIX 1: LIST OF ANNEX I AND NON-ANNEX I COUNTRIES

The UNFCCC divides countries into different groups according to their differing commitments. The Annex I and the Non-Annex I countries are listed in this appendix.

Annex I Parties include the developed countries that were members of the OECD (Organisation for Economic Co-operation and Development) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States:

Australia
Austria
Belarus**
Belgium
Bulgaria
Canada
Croatia**
Czech Republic**
Denmark
Estonia
European Community
Finland
France
Germany
Greece
Hungary
Iceland
Ireland
Italy**
Japan
Latvia
Liechtenstein**
Lithuania
Luxembourg
Monaco**
Netherlands
New Zealand
Norway
Poland
Portugal
Romania
Russian Federation**
Slovakia**
Slovenia**
Spain
Sweden
Switzerland
Turkey**
Ukraine**
United Kingdom of Great Britain and Northern Ireland
United States of America

* Observer State.
** Party for which there is a specific COP and/or CMP decision.

Non-Annex I Parties are mostly developing countries:

Afghanistan
Albania**
Algeria
Angola
Antigua and Barbuda
Argentina
Armenia**
Azerbaijan
Bahamas
Bahrain
Bangladesh
Barbados
Belize
Benin
Bhutan
Bolivia
Bosnia and Herzegovina
Botswana
Brazil
Brunei Darussalam
Burkina Faso
Burundi
Cambodia
Cameroon
Cape Verde
Central African Republic
Chad
Chile
China
Colombia
Comoros
Congo
Cook Islands
Costa Rica
Cuba
Cyprus
Côte d'Ivoire
Democratic People's Republic of Korea
Democratic Republic of the Congo
Djibouti
Dominica
Dominican Republic
Ecuador
Egypt
ElSalvador
Equatorial Guinea

Eritrea
Ethiopia
Fiji
The former Yugoslav Republic of Macedonia
Gabon
Gambia
Georgia
Ghana
Grenada
Guatemala
Guinea
Guinea-Bissau
Guyana
Haiti
Honduras
India
Indonesia
Iran (Islamic Republic of)
Israel
Jamaica
Jordan
Kazakhstan**
Kenya
Kiribati
Kuwait
Kyrgyzstan
Lao People's Democratic Republic
Lebanon
Lesotho
Liberia
Libyan Arab Jamahiriya
Madagascar
Malawi
Malaysia
Maldives
Mali
Malta
Marshall Islands
Mauritania
Mauritius
Mexico
Micronesia (Federated States of)
Mongolia
Montenegro
Morocco
Mozambique
Myanmar
Namibia
Nauru
Nepal
Nicaragua
Niger
Nigeria
Niue
Oman
Pakistan
Palau
Panama
Papua New Guinea
Paraguay
Peru
Philippines
Qatar
Republic of Korea
Republic of Moldova**
Rwanda
Saint Kitts and Nevis
Saint Lucia
Saint Vincent and the Grenadines
Samoa
San Marino
Sao Tome and Principe
Saudi Arabia
Senegal
Serbia
Seychelles
Sierra Leone
Singapore
Solomon Islands
South Africa
Sri Lanka
Sudan
Suriname
Swaziland
Syrian Arab Republic
Tajikistan
Thailand
Timor-Leste
Togo
Tonga
Trinidad and Tobago
Tunisia
Turkmenistan**
Tuvalu
Uganda
United Arab Emirates
United Republic of Tanzania
Uruguay
Uzbekistan**
Vanuatu
Venezuela (Bolivarian Republic of)
Viet Nam
Yemen
Zambia
Zimbabwe

* Observer State.
** Party for which there is a specific COP and/or CMP decision.

ENDNOTES

1 UN News Centre (2009).

2 Economy (2007).

3 Stern and Bohannon (2009).

4 Developed country commitments as Annex 1 signatories to the UNFCCC. See Appendix 1 for a list of Annex 1 and non-Annex 1 countries.

5 The relevant science and its implications have been presented quite clearly by Meinshausen, *et al*. (2009), who state that "Limiting cumulative CO_2 emissions over 2000–2050 to 1000 Gt CO_2 yields a 25 per cent probability of warming exceeding 2°C." The IPCC would thus describe this scenario as being "likely", but not "very likely" to keep warming below 2°C according to IPCC (2007b), p. 23. An assumption of Meinshausen, *et al*. (2009) is that comparably ambitious efforts to limit emissions from non- CO_2 greenhouse gases such as methane, nitrous oxide, and halocarbons are concurrently undertaken.

6 These reduction levels are at the stringent end of the ranges presented in the IPCC 4th Assessment Report for Annex 1 (25-40 per cent by 2020 and 80-95 per cent by 2050, relative to 1990 levels) for emission scenarios consistent with stabilisation at 450 ppm CO_2eq IPCC (2007a), Box 13.17, p. 776. If Annex 1 countries were less ambitious, and their reductions reached only the lower end of these ranges (20 per cent by 2020 and 80 per cent by 2050), they would occupy a significantly greater fraction of the available budget: roughly 305 Gt CO_2 (between 2010 and 2050), leaving 355 Gt CO_2 for non-Annex 1 countries to emit. Three independent analyses AOSIS (2009), UNFCCC Secretariat (2009), Wagner and Amann (2009) have examined the current Annex 1 countries' pledges and found that the aggregate implied Annex 1 reductions for 2020 fall shy of even the less ambitious end of the 25-40 per cent range.

7 If, alternatively, we assume that China's proportion is proportional to its share of non-Annex 1 population, its budget would be approximately 110 Gt CO_2.

8 The three examples given here are simple indicative paths intended to clarify the size of the budget and the significance of timing of reductions. In each path, emissions continue along recent trends, growing at 5per cent/yr until the specified year (2015, 2020, or 2025), reaching a peak level (approximately 10 Gt CO_2, 13 Gt CO_2, or 17 Gt CO_2, respectively), and then steadily declining at the stated annual rate (5 per cent, 11 per cent, and 35 per cent, respectively). (Note that these are rates of decline in emissions, not in emissions intensity.) In each of the three paths, China's total emissions over the period 2010 to 2050 would amount to 220 Gt CO_2.

9 In addition to providing the required financial and technological support, one could also imagine Annex 1 countries undertaking domestic emissions cuts greater than that assumed here (40 per cent by 2020 and 95 per cent by 2050), and thereby making more of the global emission budget available to the non-Annex 1 countries. If, hypothetically, Annex 1 entirely eliminated its emissions by 2025, it would consume 100 Gt CO_2 of the remaining budget (instead of 200 Gt CO_2), and leave 560 Gt CO_2 to the non--Annex 1 countries, of which approximately 270 Gt CO_2 might be used by China. In this case, China's emissions could peak in 2020 and then decline by 7 per cent/yr, (rather than 11 per cent/yr). This is a significant quantitative difference, but not sufficient to qualitatively change the picture.

10 In the absence of any other externality than the climate externality, China's emissions rights (in excess of their physical emissions) are compensated by a "below physical emissions" allowance of the developed countries. In practice, this would amount to developed countries buying rights from China to equalise marginal abatement costs. The allowance price would reflect the overall scarcity of the budget to reach the 2°C target. Thus, China would receive a money transfer that scales with the number of excess rights (indicating equity principles) and the allowance price (indicating the difficulty to meet the target globally). This money transfer is the economic incentive for China to sell a portion of its rights, and follow a more ambitious emissions trajectory domestically. In the presence of additional externalities such as, for instance, a technological spill-over externality, additional measures directed to raise R&D investment and deployment levels and to foster technology diffusion will be necessary.

11 Rockström, *et al*. (2009).

12 Fan, *et al*. (2009).

13 Fan, *et al*. (2009).

14 'No regrets' policies refer to policies which reduce greenhouse gas emissions with net negative costs,

because they generate direct or indirect benefits that are large enough to offset the costs of implementing these policies. In other words, there would be no regret in implementing these policies as there would be no costs involved, and may even provide benefits, even when climate change is not taken into account. 'No regrets' policies are distinct from 'win-win' policies which provide climate change and non-climate change benefits (e.g. energy security), IPCC (2001).

15 Hallding, *et al*. (2009b).

16 Hallding, *et al*. (2009a), however, the figure has been updated with new data.

17 Garnaut, *et al*. (2008), International Energy Agency (2007), Jiang (2008), McKinsey and Company (2009a). The reference trajectory for constant energy intensity and 25 per cent carbon intensity reduction is based on economic growth assumptions from Jiang (2008) and International Monetary Fund (2009). These do not account for improvements in fuel mix. The scenario with 25 per cent carbon intensity reduction per five year period is based on the assumption that China meets its national targets of (i) 20 per cent reduction in energy intensity per five year period, (ii) 20 per cent renewables in the primary energy mix by 2020. It is assumed that the increase of renewables is the same in 2010-2020 as in 2020-2030. In this scenario, no other national targets are taken into account, (e.g. reforestation targets). NB: The McKinsey projections for 2030 are given in CO_2 equivalent.

18 The trajectory is drawn on the assumption of 25 per cent carbon intensity gains per five-year period, which would be the combination of 1) rolling 20 per cent energy intensity gains, and 2) a non-fossil share of the energy mix that reaches 20 per cent by 2020.

19 Ackerman (2009).

20 Flachsland, *et al*. (2009).

21 Stanton (2009).

22 In the 2004 dataset used by Stanton (2009), China's emissions per capita place in the first decile above the median on a scale of greenhouse emissions in relation to living standards.

23 Stanton (2009) shows that in a global dataset from 2004 China had the 8th highest emission intensity 0.9 tonnes per $1,000 (PPP) per capita.

24 23 out of 30 Chinese provinces are above the 90th percentile by emissions intensity in the international dataset used in the study by Stanton (2009).

25 Stanton (2009).

26 Stanton (2009).

27 Gapminder (2008).

28 Ackerman (2009a).

29 Barrett, *et al*. (2009), Scott (2009),Wiedmann, *et al*. (2008).

30 Agarwal and Narain (1991).

31 GCI (The Global Commons Institute) (2008).

32 Baer, *et al*. (2008).

33 Fan, *et al*. (2009).

34 International Energy Agency (2007).

35 Kartha (2008).

36 Fan, *et al*. (2009).

37 Flachsland, *et al*. (2009).

38 Fan, *et al*. (2009).

39 Heaps (2009).

40 Heaps (2009).

41 International Energy Agency (IEA) (2008).

42 Ministry of the Environment and Ministry of Enterprise (2009).

43 ChinaGate (2009), World Bank (2009).

44 Ford (2009), HSBC (2009).

45 Wuppertal Institute for Climate, Environment and Energy (2009). Sustainable Urban Infrastructure: Munich Edition - Paths Towards a Carbon-Free Future. München, Siemens AG.

46 China Daily (2008), Sweco (2009), Tangshan Government (2008), Tao (2006).

47 Lans (2008), Masdar City (2009).

48 Cai, *et al*. (2009).

49 The Climate Group (2009).

50 The Climate Group (2009).

51 Economist (2009a).

52 McKinsey and Company (2009a), McKinsey and Company (2009b), UNFCCC (United Nations Framework Convention on Climate Change) (2007).

53 Reuters (2009), US Department of State (2009).

54 Cao (2009), ChinaGate (2009).

55 According to the latest IEA 'World Energy Outlook', in industrialised countries the price of a permit to emit a tonne of carbon dioxide will need to reach $50 by 2020 and $110 by 2030. In developing countries the price would need to reach $30 a tonne by 2020 and $50 by 2030, as reported by Financial Times (2009).

56 Cao (2008).

57 Edenhofer, *et al*. (2009).

58 Edenhofer, *et al*. (2009).

59 Edenhofer, *et al*. (2009).

60 Ackerman (2009b).

61 Edenhofer, *et al*. (2009)

62 Brunner, *et al*. (2009).

63 Brunner, *et al*. (2009).

64 Flachsland, *et al*. (2009).

65 Edenhofer, *et al*. (2009).

66 Flachsland, *et al*. (2009).

67 Center for Clean Air Policy-Europe, *et al*. (2008)

68 Ackerman (2009b).

69 Ackerman (2009b).

70 Ackerman (2009a).

71 World Bank (2009).

72 Fan, *et al*. (2009).

73 State Council Information Office (2008).

74 Yang and Xing (2009).

75 China Greentech Initiative (2009).

76 Edenhofer, *et al*. (2009).

77 Luderer, *et al*. (2009), Lüken, *et al*. (2009).

78 Fan, *et al*. (2009).

79 Fan, *et al*. (2009).

80 Lazarus and Polycarp (2009).

81 UNFCCC (United Nations Framework Convention on Climate Change) (2007) estimates suggest a value of 20 per cent. McKinsey and Company (2009a) provides an estimate for China of $400 (€300) billion for 2026-2030, which is roughly 40 per cent of their global estimate.

82 McKinsey and Company (2009b), UNFCCC (United Nations Framework Convention on Climate Change) (2007).

83 McKinsey and Company (2009a), McKinsey and Company (2009b), UNFCCC (United Nations Framework Convention on Climate Change) (2007).

84 Economist (2009b).

85 Stern and Bohannon (2009).

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