

4. IPCC SRES-BASED ENERGY AND EMISSION SCENARIOS FOR CHINA IN THE 21ST CENTURY

Abstract Using the global energy simulation model, TIMER, a set of energy and emission scenarios for China between 1995 and 2100 were developed based on the global baseline scenarios published by IPCC. The purpose of the study was to explore possible baseline developments and available options to mitigate emissions. The two main baseline scenarios differ in particular in the openness of the Chinese economy. Both scenarios indicate a rapid growth in carbon emissions (2.0% and 2.6% per year in the 2000–2050 period). In the mitigation analysis, a large number of options were evaluated in terms of impacts on investments, user costs, fuel imports costs and emissions. It is found that a large potential to mitigate carbon emissions in China was found, for example, in the form of energy efficiency improvement (with large co-benefits) and measures in the electricity sector. By combining all options considered, it appears to be possible to reduce 2050 emissions compared to the baseline scenarios by 50%.

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4.1 Introduction

As China is the world's most populous country with a rapidly growing economy, trends in China's energy future will have considerable consequences for both China and the global environment. Two important trends characterise China's energy use over the last two decades: on the one hand, energy intensity has fallen dramatically (by around 4% per year), and, on the other, China's primary energy consumption has more than doubled (Zhang, 2001). Greenhouse gas (GHG) emissions have increased at a similar rate. While per capita emissions are still very low, China is likely to become the world's largest carbon dioxide-emitting country in the next ten years. In view of this, there has been considerable attention paid to potential development of Chinese emissions from both scientists and policy makers (see e.g. Müller, 2001). Despite the fact that China currently still has no obligations to limit its emissions, it does seem necessary to explore the policy options for reducing GHG emissions in China. Crucial questions are, for instance, what could be the trends in China without explicit climate policies? Is it possible to significantly reduce China's emissions during the first half of this century and how? What are the costs of such policies, what could be the co-benefits? In this chapter, we explore these questions using the IMAGE/TIMER integrated assessment model and a set of newly developed storyline-based scenarios.

Future GHG emissions are the product of complex dynamic processes determined by driving forces such as demographic development, socio-economic development, and technological and institutional change. The future of these factors is highly uncertain. Various development patterns could introduce very different futures. New scenario approaches using storyline-based and multiple scenarios intend to identify some of these possible futures, by developing alternative images of how the future might unfold. These images (scenarios) can function as appropriate tools for analysing how driving forces may influence future emissions and for assessing the associated uncertainties. Such an approach has been used in IPCC's recently published Special Report on Emission Scenarios (SRES) (Nakicenovic and Swart, 2000) (see also Section 1.3.2). Using the SRES approach, we have developed several baseline and policy scenarios in this study to explore the possible development in the energy system in China and related environmental pressure. The scenarios enable us to analyse the strategic decisions involved in the different types of development, the possible impacts of climate change and possibilities for mitigation and adaptation.

In this chapter, we will first briefly discuss the process and the methodology of the research, followed by a presentation of the key aspects of baseline scenarios for China, both in terms of storyline and quantitative simulation results from the energy model. The next section will discuss several options and scenarios aimed at mitigating the Chinese GHG emissions between 2000 and 2050. Finally, the chapter will be rounded off with conclusions.

4.2 Process and methodology

In this analysis, we used the TIMER model, which provides a good description of changes within the energy system, including some of the relevant dynamics such as fuel substitution and technology development. Moreover, the energy model TIMER is directly linked with the larger framework of the integrated assessment framework IMAGE, which enables us to analyse the chain of relevant changes from driving forces to impacts of climate change (see Chapter 2).

The Integrated Model to Assess the Global Environment (IMAGE) was developed to study the long-term dynamics of global environmental change, in particular, changes related to climate change. The version used in this chapter (IMAGE 2.2) consists of a set of coupled submodels (IMAGE-team, 2001). It includes submodels related to food demand and land-use changes (Terrestrial Environment System, TES), energy demand and supply, and energy and industrial GHG emissions (Energy-Industry System, EIS), and, finally, to the role of various GHGs in the ocean and atmosphere (Atmosphere-Ocean System, AOS).

The version of TIMER applied here is TIMER 1.0. An extensive description of the model can be found in Chapter 2 of this thesis and in the TIMER 1.0 model documentation

(de Vries et al., 2001). The TIMER 1.0 model is a system-dynamics simulation model at an intermediate level of aggregation: 17 world regions, 5 energy-demand sectors (Industry, Transport, Residential, Commercial and Other) and 6–8 energy carriers (Figure 4.1). The model is a simulation model: it does not optimise scenario results on the basis of perfect foresight, but instead, simulates year-to-year investments decisions based on a combination of bottom-up engineering information and specific rules about investment behavior, fuel substitution and technology.

The time horizon in the present analysis covers the period from 1995 to 2100—although for the policy options we will focus mainly on the 1995–2050 period. The model calibration is based on historical data for the 1971–1995 period. This time horizon is in accordance with many other scenario studies, notably the SRES report (Nakicenovic and Swart, 2000). It puts short-term decisions in a long-term perspective. It should, however, be noted that in time the future becomes inherently more uncertain, and beyond the scope of current policy makers. In this study, only GHG emissions from energy use have been considered, which means that emissions and uptake from forestry and land use are not included. We will describe our scenarios mostly in terms of their carbon dioxide emissions. However, in the IMAGE model emissions of other (greenhouse) gases such as methane, nitrous oxide and sulphur dioxide are also calculated (Figure. 4.1).

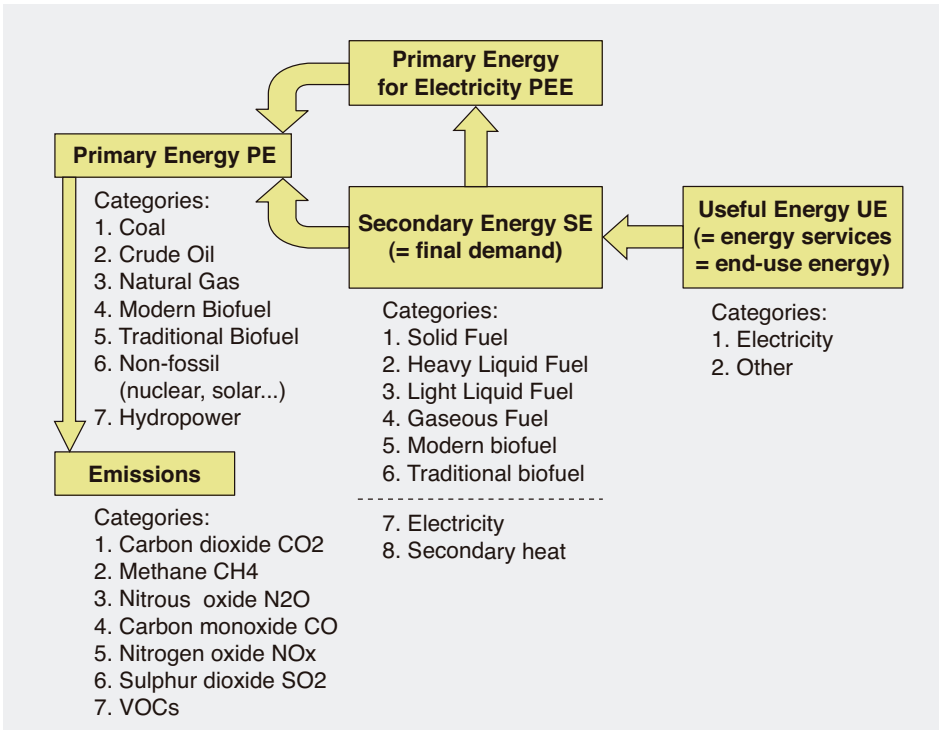


Figure 4.1 Overview of categories and calculation flows in the TIMER model.

We have gone through various steps in the process to develop our emission scenarios:

1. First, the development of storylines for China on the basis of existing global storylines from other IMAGE/TIMER projects (IMAGE-team, 2001): the storylines, reviewed by various Chinese experts, have been adjusted to achieve a degree of consensus.
2. Second, the development of a set of quantified scenarios using the IMAGE/TIMER energy model: the model serves as a means to translate qualitative storylines into consistent scenarios of quantified system variables.¹
3. Third, the development of several mitigation scenarios. These scenarios aim to identify the potential of different policy options to abate GHG emission in China.

More information on the scenarios and the assumptions made can be found in a separately published background report (van Vuuren et al., 2001).

4.3 Baseline scenarios for China

The global IPCC SRES scenarios are based on the development of narrative “storylines” and the quantification of these storylines using six different integrated models from different countries. The storylines describe many different developments in social, economic, technological, environmental and policy dimensions, but not all possible developments. They do, for instance, not include “disaster” scenarios. Moreover, none of the scenarios include new explicit climate policies. The names of the IPCC scenarios are A1, B1, A2 and B2 (see Chapter 1 and 5 of this thesis for more details of these global scenarios).

On the basis of the existing global SRES scenarios, we developed four new scenarios specifically oriented to China. Two of the scenarios are described here in detail, while the other two are essentially used to indicate the larger range of uncertainties related to baseline development. The new scenarios represent some mainstream views in China and provide sufficient contrast for policy evaluation. None of the scenarios includes explicit climate policies.

In the next section we will discuss the scenario assumptions and results. Appendix 4.1 gives an overview of the major assumptions made within the TIMER model for the Chinese baseline scenarios. The assumptions made for the other global regions have been maintained as given in the SRES scenarios (IMAGE-team, 2001). Table 4.1 summarises some of the results, comparing China with Western Europe and USA.

¹ For this purpose, we have adjusted the existing TIMER 1.0 model to describe mainland China, instead of the East Asia region included in the normal TIMER model used at RIVM. The East Asia region of IMAGE 2.2 includes China, North and South Korea, Taiwan, Mongolia, Hong-Kong and Macau.

Table 4.1 Kaya indicators for China and selected regions under scenario A1b-C and B2-C*

		Historic		A1b-C		B2-C			
		1990	1995	2010	2030	2050	2010	2030	2050
Population (million)	China	1,158	1,211	1,389	1,525	1,598	1,389	1,525	1,598
	(growth rate)		0.9%	0.9%	0.5%	0.2%	0.9%	0.5%	0.2%
	USA	257	267	305	352	386	305	352	386
	Western Europe	379	384	407	425	426	407	425	426
	World	5,281	5,601	6,897	8,235	8,905	6,897	8,235	8,905
GDP per capita (US\$1995)	China	357	578	1611	4461	10228	1495	3594	7486
	(growth rate)		10.1%	7.1%	5.2%	4.2%	6.5%	4.5%	3.7%
	USA	24,727	26,316	38812	52704	72531	37613	46977	58274
	Western Europe	20,122	21,636	29563	44332	62065	28308	37547	46126
	World	4,705	4,830	6388	10866	20789	6084	8681	12945
Energy intensity (MJ/ppp\$) ⁱⁱ	China	34.4	27.8	18	13.4	10.7	17.2	12.1	9.8
	(growth rate)		-4.2%	-2.9%	-1.5%	-1.1%	-3.2%	-1.7%	-1.0%
	USA	11.9	11.4	9.2	7.5	5.6	9.1	6.8	4.8
	Western Europe	7.7	7.4	6.9	6	4.9	6.6	5.2	3.9
	World	12.2	11.6	10.1	8.4	6.3	9.8	7.7	5.8
Carbon intensity (kg-C/GJ)	China	18.8	19.1	19.8	18.9	17.6	19.8	19.2	18.6
	(growth rate)		0.3%	0.2%	-0.2%	-0.4%	0.2%	-0.2%	-0.2%
	USA	18.4	18.3	17.9	16.9	15	17.7	15.3	12.5
	Western Europe	17.4	17	16.6	15.6	13.9	16.4	14.6	11.2
	World	16.4	16.2	16.8	16.8	14.9	16.6	16	14.1
CO ₂ (billion tonnes)	China	0.7	0.9	1.6	2.6	3.8	1.4	2	2.7
	(growth rate)		5.2%	3.9%	2.5%	1.9%	3.0%	1.8%	1.5%
	USA	1.4	1.5	2.1	2.5	2.5	1.9	1.8	1.4
	Western Europe	1	0.9	1.3	1.6	1.6	1.2	1.1	0.8
	World	5.7	5.9	9.6	16.4	20.9	8.8	11.6	11.9
CO ₂ per capita (tonne)	China	0.6	0.7	1.1	1.7	2.4	1	1.3	1.7
	(growth rate)		3.1%	3.1%	2.2%	1.7%	2.4%	1.3%	1.4%
	USA	5.6	5.7	6.8	7.1	6.4	6.3	5.1	3.6
	Western Europe	2.5	2.5	3.2	3.8	3.8	2.9	2.6	1.9
	World	1.1	1.1	1.4	2	2.4	1.3	1.4	1.3

Source: TIMER model results, based on underlying data from ERI (China) and RIVM's international database (other countries).

* Since the time period in which this research was performed (2001), the Chinese emissions have been revised upward. As a result they are already near the USA emissions levels in 2010. While this fact influences some of the absolute numbers in this chapter, it has no real influence on the major trends.

ⁱⁱ Energy intensity has been expressed in terms of purchasing power parity dollars. By correcting for differences in purchasing power, energy intensity better reflects real differences in energy efficiency – although energy intensity is still also influenced by other factors such as the structure of the economy.

4.3.1. A1b-C Scenario: an “open” China in a globalised world

The first scenario follows the storyline for the SRES A1b scenarioⁱⁱⁱ, describing a case of rapid and successful economic development both in China and the rest of the world. Globally, the fast economic development is driven by such factors as human capital (education), innovation and free trade. We assume that China will continue to pursue its open-door policies, thus enabling strong technology development. By the end of the 21st century, China will almost have caught up in income with the OECD countries, the service sector (tertiary sector) showing the largest growth, with the size in the total economy increasing from about 34% in 2000 to about 60% in 2050 (see also Table 4.1). The population growth path in China follows the current expectations of the planning commission—in which population reaches a level of around 1.6 billion by 2050 and then decreases—to around 1.5 billion in 2100. The economic development in the A1b-C scenario provides support for technology R&D and innovation. As globalization allows for rapid spread of technologies, renewable energy and other clean energy technologies will become available on a large scale.

As a result of economic growth and the orientation to material-intensive lifestyles, the demand for energy increases rapidly. Per capita consumption of primary energy increases from 37 GJ per capita in 1995 to more than 150 GJ per capita in 2050. The latter is equal to the current energy consumption of many OECD countries. Energy demand grows fastest in transport, still a small sector in 1995 but representing 25% of total energy use in 2050. In terms of end-use, traditional biofuels and coal rapidly lose market shares. Traditional biofuels are replaced as a consequence of the “modernization” process. Coal is under pressure in the residential and service sectors due to its inherent environmental and comfort inconveniences. Electricity and natural gas, with their grid character, wide applicability and local cleanliness, rapidly gain market shares. Oil also gains market shares, along with the growing transport sector, but starts to feel competition from both natural gas (LNG) and biofuels from 2020 onwards (Figure. 4.2). At the moment, electricity generation in China is dominated by coal-fired power plants. In the A1b-C scenario, this situation changes only slowly, with natural gas and later zero-carbon options making inroads. The reason for this is the strong competitive position of coal in China. Increases in the use of nuclear power and hydropower are substantial—but both energy sources still cover only 5–10% of total primary inputs in 2050.

The current energy intensity (GJ/ppp\$) in China is considerably higher than the other regions caused by such factors as China’s reliance on heavy industry and energy inefficiency in industry and electric power generation (see Table 4.1; 27.8 in China versus 7.4 GJ/ppp\$ in Western Europe). In the A1b-C scenario, rapid technology transfer spurred on by free trade allows China to close the gap in energy intensity compared to OECD

ⁱⁱⁱ There are three subfamilies in the A1 group; these are based on assumptions regarding the energy system. The A1b-C scenario describes a world with balanced energy technology, developed in terms of supply options; while, the other two sub-families describe a technology development that is either geared towards fossil fuels (A1f) or new technologies (A1t).

countries by about a factor of 2. As a result, primary energy use per year grows at rates slightly lower than those in the past (2.8% in the 2000–2050 period versus 4.0% over the last 10 years) (Figures 4.2–4.5). Gradually, energy use will become less dominated by coal. In this scenario, the huge demand for energy, the relative shortage of energy resources and the open markets imply that China will depend more and more on international energy resources. More than 20% of the domestic demand will have to be met by the imported energy by the middle of this century. For oil and natural gas, these percentages are far higher: 80% and 50%, respectively, in 2050.

Investments in energy will increase gradually, reaching about US\$ 200 billion in 2020, 520 billion in 2050 and 1660 billion in 2100. It will clearly be a challenge for China to be able to realise these investment rates—certainly in the first part of the century. The ratio of investment in energy to GDP is about 4.5% in 2000, slightly increasing to 4.7%

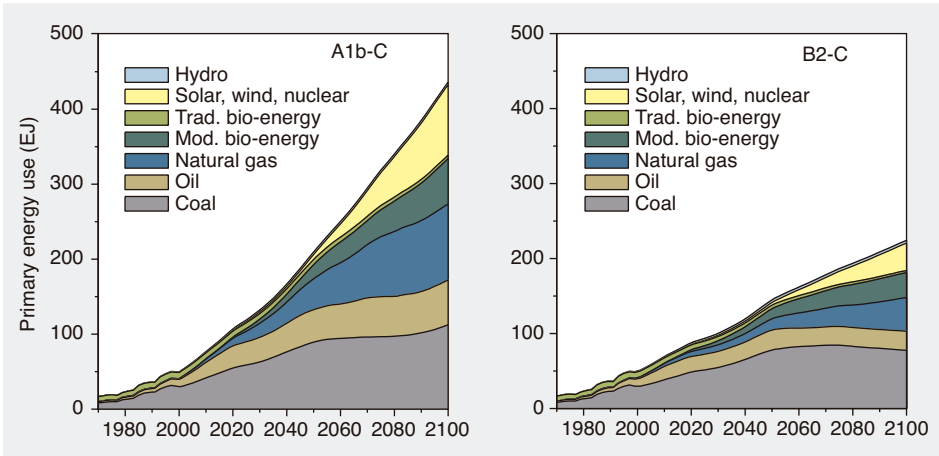


Figure 4.2 Primary energy use according to the A1b-C (left) and B2-C (right) scenarios. (NTE : Non-thermal electricity, such as nuclear, solar and wind)

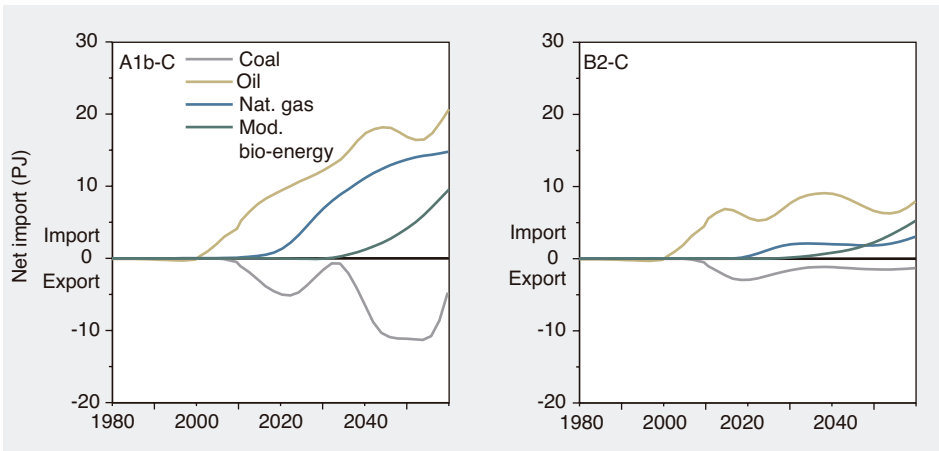


Figure 4.3 Net trade in energy carriers according to the A1b-C (left) and B2-C (right) scenario.

in 2020, decreasing to 3.1% in 2050 and further decreasing to 1.8% in 2100. This trend reflects the decreasing relative role of energy in the economic development.

Several factors will have an impact on fuel prices. On the one hand, energy resources will become less abundant and more difficult to develop, which raises the price, while on the other, people have more experience and more advanced technologies, which reduces the price. In the case of A1b-C, the prices of oil and natural gas are relatively stable at US\$4 per GJ up to 2015; due to slow depletion of cheap Middle East oil and gas prices, these increase slowly afterwards to US\$7 per GJ in 2050. The price of coal will continue to increase in the whole simulation period; however, its costs are much lower than those of oil and gas.

4.3.2. B2-C Scenario: China geared to solving regional environmental problems

This scenario follows the SRES B2 storyline. It assumes a slightly lower economic growth (see Table 4.1) with limited trade and technology transfer among world regions. The basic consideration in this scenario for China is that economic development will utilize domestic resources so as to maintain equity for the future, while maintaining balance among regions as well as between urban and rural areas. Environmental issues—food and water, air pollution and the like— are recognized as serious problems and make environmental sustainability an important priority. This scenario can be described as regional stewardship. The growth of the population is assumed to be the same as in the A1b-C scenario. The energy system will to a larger extent rely on domestic resources, while technological progress is lower for both energy production and end use because of limited trade and transfer. Coal use in this scenario will be based on clean coal technology.

The assumption of the B2-C scenario is that development in China will be oriented to solving regional problems using predominantly domestic resources. As the main energy resource of China is coal, the strong focus to preserve local environmental resources requires the development in this scenario of clean coal technologies. In addition, energy efficiency will be important to prevent demand for oil and natural gas growing too fast. Thus, an important difference between the B2-C and A1b-C scenarios is the energy demand, which, by the end of the century, is only about half of that in the A1bC scenario. The structure of energy use per sector follows a similar path to that in the A1b-C scenario: the share of industry decreases while the share of transport increases. However, the changes are slower than in the A1b-C scenario. Although the share of industry will slowly decrease to 38% by the end of the century, industry will still be the largest energy consumer.

With respect to the structure of primary energy demand by energy carrier, the share of natural gas, modern biomass, solar and wind energy will increase. However, in comparison to the A1b-C scenario, China will depend on domestic energy resources, which means that coal will continue to be the most important energy source in China even

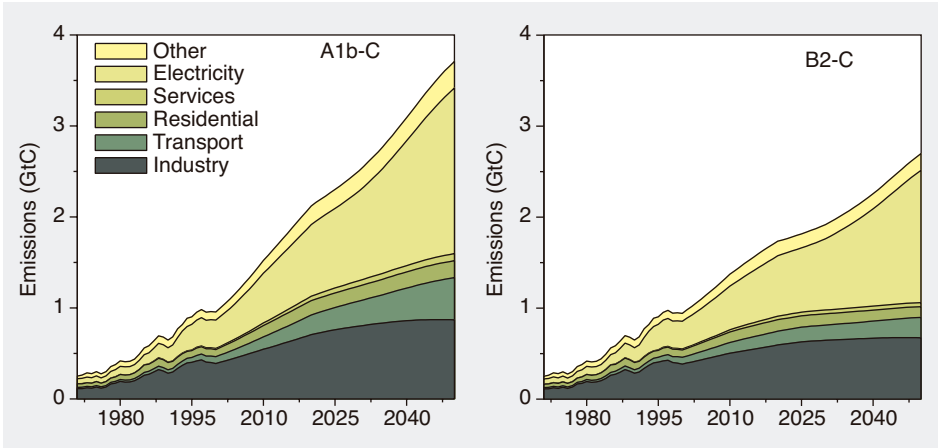


Figure 4.4 Carbon dioxide emissions following the A1b-C (left) and B2-C (right) scenarios.

though its share will gradually decrease to 53% in 2050 and 34% in 2100. Fuel trade is lower in terms of both the absolute value and the ratio to total primary energy use compared to that in the A1b-C scenario, although some imports of oil and natural gas seem to be inevitable.

In this scenario, investment in energy are smaller than in the A1b-C scenario but the ratio of energy investment to GDP will follow the same trend as in the A1b-C scenario. The structure of energy investment will also be similar to that in the A1b-C scenario; fossil fuel will lose its share while non-thermal electricity (nuclear and/or renewables) will gradually gain a larger share. Fuel price development shows one remarkable difference. In the B2-C scenario, China depends more on domestic energy resources. Due to depletion of domestic oil and natural gas resources in the late 2010s, the price of these products, especially the price of natural gas, will therefore rise sharply. As a result, the difference between the coal price, and the oil and natural gas prices, are larger than in the A1b-C scenario in the first half of the 21st century.

4.3.3. Energy-related carbon dioxide emissions

In 1990, carbon dioxide emissions of China were 0.68 GtC, which rapidly increased to 0.90 GtC in 1995. In contrast, between 1996 and 1999 China experienced a decrease in the emissions of carbon dioxide as a consequence of a set of short-term trends (reduction in economic growth and improvement in coal quality) and longer-term trends (e.g. efficiency improvement) (Sinton and Fridley, 2000). We have captured some of the relevant factors in our model simulations, for example, as strong improvements in autonomous energy efficiency. In both scenarios, however, the decline in emissions has only a temporary effect. Emissions increase up to 2050 by a factor of 2.7 and 3.8, in B2-C and A1b-C, respectively. For the mitigation scenarios discussed further in this chapter, it is important to know where the emissions come from. In both scenarios, electricity generation—based on coal-fired power plants—will become the most impor-

tant source of emissions (around 50% of all emissions in 2050). The second important source is represented by emissions from (coal use in) industry. Although transport is projected to become a much more important sector in total energy use in China, its share in carbon emissions still remains relatively low.

In both scenarios Chinese carbon dioxide emissions will have surpassed those of the USA in the near future and further increase to 2.7 billion tonne carbon under B2-C, and 3.8 billion tonne carbon under A1b-C in 2050 (Table 4.1). The differences reflect mainly the differences in assumed economic growth rate. It should be noted, however, that the carbon dioxide emissions per capita in China are still very low. Per capita emissions will be close to the world average around 2030 and 2050 under B2-C and A1b-C, respectively. Compared to GDP per capita, the relative convergence of China's carbon dioxide emissions per capita to global averages is more rapid. This is because China relies more on carbon-intensive energy resources, especially under the B2-C scenario.

4.3.4. Alternative scenarios: B1-C and A1f-C

The two scenarios described above are only two of many possible developments in China. Two other scenarios in the SRES set, elaborated upon for China, might be of interest here. These are the B1-C scenario, a scenario based on globalization but time-oriented towards sustainable development, and the A1f-C scenario, which shares many of its assumptions with the A1b-C scenario but assumes stronger technology development for fossil fuels and less development for new technologies. As for the other two baseline scenarios, the B1-C and A1f-C scenarios assume no explicit climate policies.

The B1 scenario describes a world dominated by high levels of environmental and social consciousness and successful global cooperation. Compared to A1b-C, economic development is slightly slower and there will be a much stronger trend towards that of a service economy. In B1-C scenario, we assume China will not adopt the current energy- and material-intensive lifestyles of the Western world, but choose for a less material, more service-oriented lifestyle (the Western countries will also move in this direction in B1). In such a scenario we see a rapid improvement in efficiencies. The 2100 energy consumption of 70 GJ per capita is relatively low but comparable to the projected OECD average in that year and based on its efficiency, this energy consumed is able to facilitate a much higher level of welfare. The environmental consciousness assumed means that in the scenario, coal use declines and more environmentally friendly fuels such as natural gas and modern biofuels gain market shares. Technology development will also enable extensive use of solar and wind power.

The A1f-C scenario describes a world with strong economic growth and a supply orientation in the energy system. This implies a strongly growing energy demand and large investments in energy supply. Penetration of alternative fuels to fossil fuels is slowed down significantly as we assume more rapid technological development for the latter and slower development for the former. As a result, the energy system remains domi-

nated by coal over the whole century, and later on, also by oil and natural gas, which will take over the use of coal in the transport and building sectors.

Figure 4.6 summarises the four scenarios under three main characteristics: energy use per capita, carbon emissions per unit of energy use (carbon factor) and carbon dioxide emissions. In the A1f-C scenario Chinese carbon dioxide emissions are shown to increase to 8 GtC, a level about 30% higher than the current global emissions, caused by high energy use and a very high carbon factor. In the A1b-C scenario emissions reach a level of 30% below those in the A1f-C scenario, the difference mainly being caused by differences in the energy mix (the carbon factor)—with non-fossil-based fuels gaining a significant market share in the second part of the century. The B2-C scenario results in carbon dioxide emissions that are about a factor 2 lower than in A1b-C, pushed by its lower energy use. In fact, the relative share of coal in B2-C is higher than in

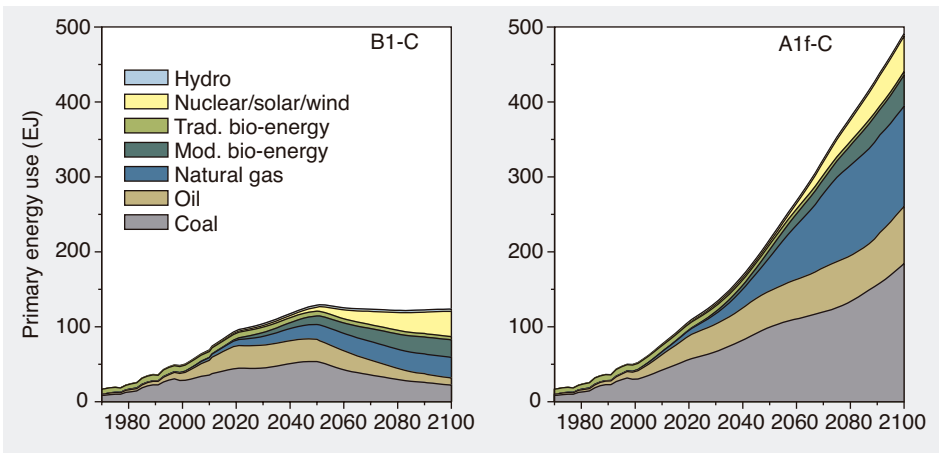


Figure 4.5 Primary energy use in the alternative B1-C (left) and A1f-C (right) scenarios (NTE : Non-thermal electricity, such as nuclear, solar and wind)

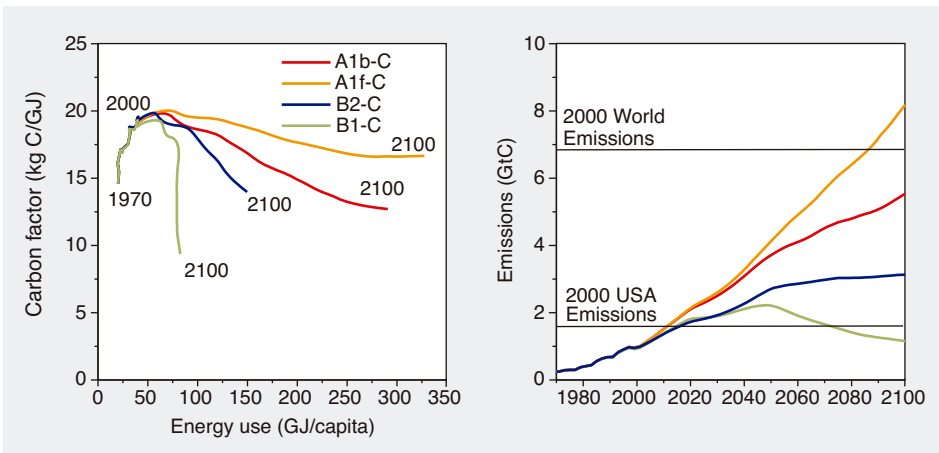


Figure 4.6 Trajectory of energy use (GJ per capita) and carbon factor (tC/GJ) (left), and CO2 emissions (right) in the four scenarios developed for China in this analysis.

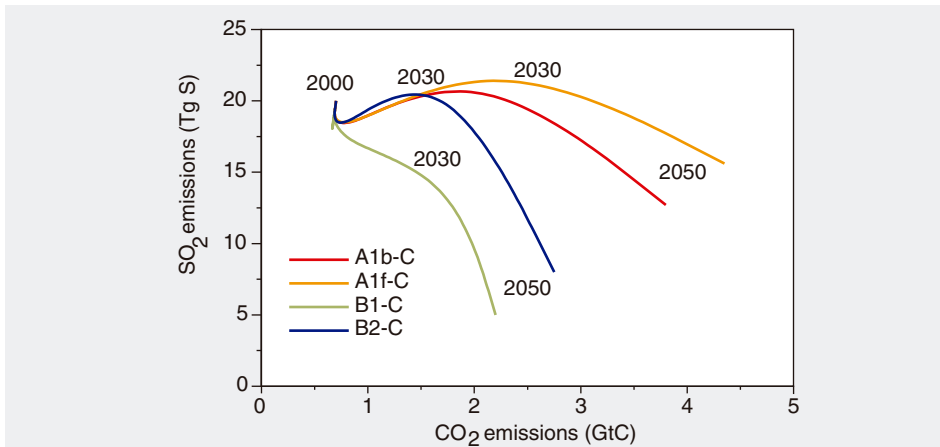


Figure 4.7 Carbon and sulfur emissions under four scenarios.

A1b-C (reflected in a higher carbon factor). Finally, the B1-C scenario sees emissions doubling in the first half of the century—but consequently declining to slightly above the present level in the second half. This decline compared to A1b-C is caused by both low energy use per capita (efficiency and structural change) and major changes in the energy supply.

The current level of sulfur emissions in China (around 18 Tg SO₂) contributes to both regional air pollution (in particular, acidification) and urban air pollution. In addition, sulfur emissions can have an important impact on climate change. Therefore, it might be worthwhile to have a look at trends in these emissions. In all scenarios, we have assumed that the Chinese government will intensify its effort to reduce sulfur emissions. However, the level of effort employed here differs—and obviously so does the energy mix. In Figure 4.7, where the carbon emissions of the scenarios are plotted against the sulfur emissions, the main differences between the scenarios are caused by the high level of environmental protection in B1-C and B2-C and the less strict protection levels in A1b-C and A1F. In addition, however, we can see that sulfur emissions are also a function of the changes in energy mix—B1-C has fewer sulfur emissions than B2-C; A1b-C has fewer emissions than A1F. In other words, lower carbon emissions coincide with lower sulfur emissions. The sustainability-oriented B1-C scenario benefits in particular from this.

4.3.5. Comparison with other scenario studies

The scenarios presented here can be compared to other baseline scenarios. Figure 4.8 shows a set of recent baseline scenarios taken from various studies, in addition to the historic trend between 1990–1999 (IEA, 2000; Sands and Kejun, 2001; US DoE, 2001; Weyant, 2001). All scenarios shown expect emissions to increase—with growth rates ranging from 2.5% to 4.5% per year. Both the A1b-C and B2-C scenarios lie within the range drawn up by these baseline scenarios. Up to 2020, A1b-C follows the emission trend of the World Energy Outlook (IEA, 2000) while B2-C ends up very near to the pro-

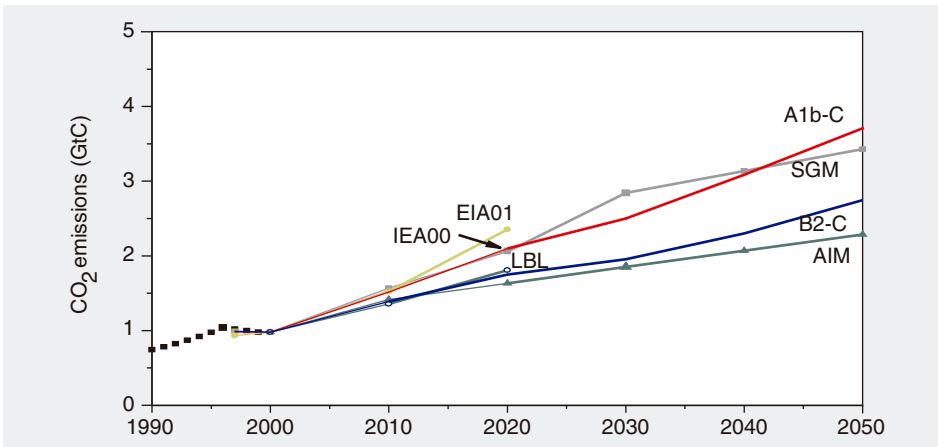


Figure 4.8 Carbon dioxide emissions in different baseline scenarios. (EIA indicates the projection by Dof, 2001. IEA the projection by IEA, 2000. LBL the projections by Sinton and Fridley, 2000. SCM the projection by Sunds and Kejun, 2001 and AIM the work of the AIM model)

jection of Sinton and Fridley (2000). Both scenarios tend to be slightly high compared to other scenarios in 2050, reflecting the storylines of the two scenarios (high energy demand in A1b-C and reliance on domestic coal resources in B2-C).

4.4 Mitigation scenarios for China

4.4.1. Policy needs for China

In the previous section we saw that baseline developments are likely to lead to considerable increases in emissions of carbon dioxide and thus will also lead to impacts on the global climate. Although developing countries have no obligations so far, the required reductions to prevent severe climate impacts need, in the long-run, participation from both developed and developing countries. In the next section we will attempt to explore the possible policy options for GHG emission reduction by matching sustainable development paths in China and their effects.

4.4.2. The context for and content of climate change policies in China

China is presently in a stage of rapid industrialization, with rising incomes, increasing urbanization and a decline in the share of the agricultural sector in the economy. Although these societal changes can be associated with a more general process of “modernization”, there are also various circumstances that are specific for China. Hence, we have to carefully investigate the energy and associated systems in China, if policies to reduce GHG emissions are to be recommended. Increasingly, the need for a more sustainable development pattern than the one taken by presently industrialized countries is felt in the less industrialized regions of the world. This is as much a consequence of

the perceived local environmental threats as of the possible global consequences of unsustainable practices. China has recognised the necessity of climate change abatement action in response to UNFCCC, which was ratified by China in 1992. In fact, climate change could be an important factor for the Chinese government in designing future environmental development in the framework of sustainable development, a long-term strategy set up by government. Many elements of climate policy can support such a longer-term strategy in the form of co- or ancillary benefits.

For the sake of convenience, we distinguish the following components of climate policies:

- (Climate change) policies: any action which interferes with the development path in the baseline scenario under discussion;
- Measures: the physical changes within the energy system (in fuel use, technology, reduction of energy demand, emission control, etc.) which influence the GHG emissions;
- (Policy) instruments: the political actions and mechanisms (such as subsidies, low-interest loan provision and educational campaigns) that are instrumental in implementing and realising the policy measures. The set of policy instruments can be subdivided into several clusters, including economic instruments, regulation, technology support and the so-called “social instruments” (e.g. information campaigns).

in each of the scenarios outlined in the previous section, there is a range of possible options and measures for GHG emission reduction that could be part of a longer-term climate change mitigation plan or strategy. Some of such options and measures are conceivable within both scenarios from the perspective of economic, political and societal feasibility and desirability. Others are not, in the sense that they will be attractive in the one scenario and unattractive, ineffective or hard to imagine in the other. However, in the development of global mitigation scenarios, the “SRES” modelling teams used the quantitative emission pathways of the various storylines at the start of their analysis, but hardly use the storylines to constrain the possible set of measures and/or policies that could be applied (Morita et al., 2000; IPCC, 2001). Here, we have followed a similar approach, but Table 4.2 still indicates the applicability of the various policy options, measures and instruments explored by us with the TIMER energy model within the context of the two baseline scenarios. In other words, for each instrument, we indicated how likely we considered the implementation of this instrument under each of the scenarios; however, in our quantitative exercises we considered all options.

A few important features of these simulations with the TIMER model should be noted:

- Population and economic activity trajectories are exogenous; these are taken from the baseline scenarios without any feedback from the energy system being taken into consideration.
- The TIMER model is not an optimization model, but simulates a complex interplay of decisions within the energy system. Hence, the analysis is often based on expert

judgement about which policy options and measures are interesting to explore, separately or in combination. The evaluation of the results is not in terms of an objective function but of various relevant system variables such as (changes in) investments, user costs and emission reduction.

- TIMER includes endogenous technology dynamics that have important cost-reducing effects if a technology is pushed by subsidies, demonstration projects and/or standards. For instance, use of energy efficiency measures lowers the cost of such energy-saving measures through learning-by-doing from accumulated energy-efficiency investments.
- As for all models, the quantification of policies is constrained by the characteristics of the TIMER model. Many of the complex, region-specific social dimensions of the determinants of GHG are absent so one has to rely on proxy variables and on storyline-related interpretations.
- A method to induce different abatement measures in TIMER is to attach a price to carbon emissions (by means of carbon levy or tax). Such a price generates a range of responses, such as investments in energy efficiency, fuel substitution and investments in non-fossil options. In TIMER, such a tax does not have any impact on the economic activity trajectory.

It should be kept in mind that these policy options and measures have to be introduced and implemented in a large field of competing policy interests. Sometimes, such other policies—for instance, population, employment, or health—have large impacts on the GHG emission path and are, as such, part of the baseline storyline and scenario.

4.5 Results for policy scenarios

This study dealt with three types of model experiments:

1. Exploring the system response by introducing a carbon tax during a certain period and at various levels.
2. Exploring the system sensitivity for specific options and measures.
3. Exploring a mitigation scenario by calculating the carbon emission reduction for an increasingly extensive package of the policy options and measures mentioned under point 2.

4.5.1. Responses to a carbon tax

One of the policy instruments that could be used to reduce carbon emissions is a carbon tax. Many studies have indicated that attaching a price to carbon emissions (e.g. carbon taxation) could be a very cost-effective instrument for inducing a series of measures to be taken in the energy system. The use of a tax allows for a large flexibility among end-users and investors in the choice of the actual measures taken. In models, applying a carbon tax in the system is often also used to obtain an indication of the possibilities of other instruments.

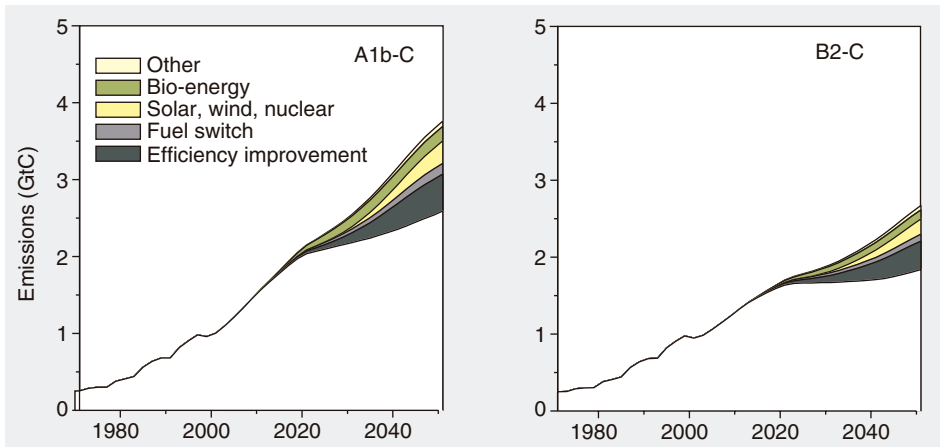


Figure 4.9 Attribution of carbon savings induced by US\$30 per tC carbon tax in baseline scenarios.

Figure 4.9 shows that a carbon tax, gradually introduced from 2015 and reaching a maximum value of US\$30/tC up to 2030, reduces the Chinese carbon dioxide emissions by 30% in both scenarios. To show the contribution of various reduction measures, we have allocated all avoided carbon emissions to four different clusters: the effects of energy-efficiency improvement, the effects of additional use of modern biofuels, the effects of additional use of non-thermal electricity (in particular, solar and wind) and the effects of fuel switching among fossil fuels^{iv}

In the first 15 years after the introduction of the tax in the A1b-C scenarios, reductions are dominated by a fuel switch from coal to other fossil fuels; to a slightly lesser extent this is also the case in the B2-C scenario. However, after this period the role of the tax declines rapidly as fossil fuels, including natural gas, are replaced by non-fossil options. Over the whole period 2015–2050, energy savings contribute most to avoided carbon dioxide emission. From 2030, the effect of renewable mitigation options starts to become more and more important. Other indirect impacts of the carbon tax are discussed further in this chapter.

We can obtain some idea of the marginal abatement costs of emission reductions in China by exploring the system's response to different levels of carbon tax. Figure 4.10 shows the response in two regions (China and Western Europe) for a hypothetical carbon tax introduced in 2000 for two different years, 2010 and 2030, within the A1b-C scenario. The figure shows that significant emission reductions can be achieved in China at relatively low taxes—certainly in comparison to Western Europe. The fig-

^{iv} It should be noted that the allocation, particularly the order, will depend somewhat on the methodology chosen. Here, first energy savings have been allocated first, then biofuels and non-thermal electricity and, finally, fuel-switch. Because of the sequence chosen, the effects of the latter are limited only to the changes in the remaining use of fossil fuels, after energy savings and additional non-fossil options have been accounted for.

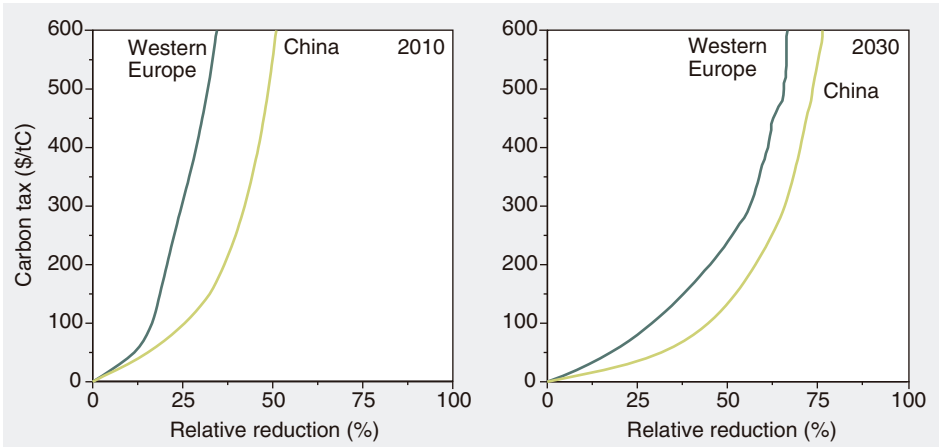


Figure 4.10 Relative emission reduction as a function of carbon tax applied for 2010 and 2030 in scenario A1b-C.

ure also shows that significantly larger emission reductions can be achieved in 2030 with the same energy tax (introduced in 2000) as in 2010. This is a function of two important mechanisms within TIMER. First of all, delays within the systems in terms of capital turnover and response time prevent the system from responding immediately to price pressure. Secondly, action taken in response to the tax is assumed to accelerate technology development by means of learning-by-doing, which enlarges the potential for reduction in later periods.

The comparison of the carbon tax response curve of the two regions gives us some idea of the potential for use of the Clean Development Mechanism to meet the required emission reductions of Annex-I countries through actual reductions in non-Annex-I countries. Under the Kyoto Protocol, Western Europe has to reduce its emissions by 8% compared to 1990; this is estimated to be in the order of 20–30% compared to the baseline (e.g. RIVM et al., 2001). Originally, studies expected that the final carbon price could be around US\$50 per tC (e.g. RIVM et al., 2001) – but after the Marrakech accords and especially the decision of the USA not to ratify the Kyoto Protocol, price estimates are generally around US\$10 per tC (see den Elzen and de Moor, 2001). Still, when we using the higher price as a benchmark of future climate agreements, in China, projects corresponding to a carbon price of US\$50 per tC could reduce emissions by 15–20% compared to its baseline— or in other words reduce emissions by 0.2–0.3 GtC. This is an enormous potential for emissions reduction making China potentially very attractive for CDM projects.

4.5.2. Carbon emission reduction: policy options and measures

To get a better idea of the potential impacts of different policies between 2000 and 2050 in China, we implemented a series of modelling experiments. In most cases we chose measures that we regard as “moderate” since they are based on energy policies that are under discussion for the coming decade(s) in Western Europe. The measures

Table 4.2. Overview of policy options/measures, instruments and applicability

Policy measure	Possible policy instruments	Applicability		Implementation explored in the modelling experiment
		A1b-C	B2-C	
1. Incentives for energy-efficiency investments	<ul style="list-style-type: none"> • taxes/subsidies • low/zero-interest loans • information campaigns • appliance labels/ standards • investment in public transport systems • voluntary agreements with industry 	+/- + - + + ++	++ ++ ++ ++ ++	Reducing the gap in final energy intensity between Western Europe and China in 2050 by another 30% beyond the baseline.
2. Energy taxation inducing a series of responses	<ul style="list-style-type: none"> • tax on gasoline/kerosene as part of "greening tax" policy 	+	+++	Adding an energy tax –equal for all fuel types – for industry and transport equal to current Western European tax levels for oil and gas
3. Influencing market penetration of secondary energy carriers	<ul style="list-style-type: none"> • taxes/subsidies, e.g. on natural gas or biofuels • emission standards 	+/- +	+ +++	Reducing the use of coal in the building sector to zero
4. High-efficiency, gas-fired Combined-Cycle (CC) in central electric power generation	<ul style="list-style-type: none"> • technology and emission standards • institutional reforms • RD&D projects • Investments 	++	++	In 2050, 15-20% of all electricity is generated by gas-fired combined cycle.
5. Advanced Clean Coal (ACC) options including Integrated Gasification Combined Cycle		++	++	All new coal power plants from 2010 onwards is highly efficient.
6. Reducing transmission losses		++	++	Losses in distribution and transmission of electricity are reduced in 2050 to the level of OECD countries (8%).
7. Increasing the share of nuclear power generation	<ul style="list-style-type: none"> • technology and emission standards • portfolio standards / renewable energy obligation 	++	+	Use of nuclear power is increased from 10% (A1b-C) and 7% (B2-C) to 20% of all electricity generated.
8. Increasing the share of renewables such as solar and wind in electric power	<ul style="list-style-type: none"> • institutional reforms • RD&D projects • investments 	++	++	Use of new renewables in electric power generation is increased from 7% (both A1b-C and B2-C) to 20% of all electricity generated. In 2020, the required share is 10%.
9. Increasing the share of hydropower generation		++	+	Use of hydropower is increased from 68% to 90% of maximum potential of 378 GW.
10. Accelerating the penetration of biomass-derived fuels	<ul style="list-style-type: none"> • RD&D projects • tax exemption / subsidies to farmers • low/zero-interest loans • portfolio standards / renewable energy obligation 	+	+++	Overruling of market dynamics with expansion targets; 10% market share in oil/gas market 2020, 20% market share in 2050
11. Carbon taxation inducing a series of responses	<ul style="list-style-type: none"> • carbon tax on fuel use in all sectors 	++	++	Implementation of a US\$30 carbon tax.

+++ : very well applicable, ++ well applicable; + applicable; +/- might be applicable; - poorly applicable.

explored are discussed in Table 4.2, with the exact implementation in the model indicated in Appendix 4.2.

Table 4.3a and 4.3b show the mitigation effectiveness and cost aspects of these 11 policy options and measures, for the A1b-C and the B2-C baseline scenarios. Each policy option/measure can be evaluated on four criteria: 1) effectiveness, 2) financial feasibility, 3) political feasibility and 4) strategic consequences. Here, we used the following indicators:

1. effectiveness: emissions reduction with respect to baseline;
2. financial feasibility: increase in energy system investments;
3. political feasibility: additional user costs;
4. strategic consequences: changes in total net costs of imported fuels.

Highly efficient power plants such as combined cycle and IGCC are able to considerably reduce emissions in China. This is particularly the case for IGCC if coal remains the dominant fuel in electric power. The strategy to develop coal-based clean technology could have both environmental and economic benefits, especially if China becomes a leader on this technology. It should be noted that improvement of electricity distribution can further reduce emissions by 1%.

In China alternatives for fossil fuel in the power sector up to 2050 are likely to remain poor competitors of thermal power plants with large supplies of very cheap coal. Thus, policies aiming to bring down the costs of these alternatives (either nuclear, wind or

Table 4.3a Introducing policy options/measures in China using the A1b-C baseline scenario

Measure/ Instrument (compare Table 4.2/Appendix 4.2)	Carbon emissions (compared to baseline)		Energy investments (compared to baseline)		User costs (compared to baseline)		Fuel balance of trade (compared to baseline)	
	2020	2050	2020	2050	2020	2050	2020	2050
Demand side								
1. Energy efficiency	-6.2%	-10.8%	6%	9%	2%	3%	-15%	-28%
2. Energy taxation.	-2.0%	-3.8%	2%	1%	11%	15%	4%	5%
3. No coal use in buildings	-1.4%	-0.4%	1%	0%	3%	1%	7%	3%
Fossil-based electricity								
4. Combined cycle	-0.5%	-4.9%	0%	2%	0%	2%	2%	10%
5. IGCC	-5.3%	-9.4%	4%	8%	1%	3%	0%	0%
6. Improved distribution	-1.0%	-1.0%					0%	0%
Non-fossil fuels								
7. Nuclear	-0.4%	-9.6%	1%	6%	0%	2%	0%	-4%
8. Solar /wind	-2.3%	-6.2%	7%	4%	2%	2%	0%	-2%
9. Hydro	-2.8%	-2.9%	-1%	-1%	0%	0%	-1%	-2%
10. Biofuels	-0.2%	-0.7%	0%	-1%	0%	1%	0%	6%
Carbon tax								
11. 30 US\$ per tC	-6.5%	-30.6%	6%	16%	20%	20%	28%	30%

Note: IGCC = Integrated Gasification Combined Cycle; furthermore, numbers cannot simply be added up as they relate to individual model experiments.

Table 4.3b Introducing policy options/measures in China using the B2-C baseline scenario

Measure/ Instrument (compare Table 4.2/Appendix 4.2)	Carbon emissions (compared to baseline)		Energy in- vestments (compared to baseline)		User costs (compared to baseline)		Fuel balance of trade (compared to baseline)	
	2020	2050	2020	2050	2020	2050	2020	2050
Demand side								
1. Energy efficiency	-7.6%	-14.4%	7%	12%	2%	1%	-17%	-28%
2. Energy taxation.	-2.0%	-3.6%	1%	3%	15%	20%	4%	0%
3. No coal use in buildings	-0.9%	-0.5%	1%	1%	2%	1%	5%	1%
Fossil-based elec- tricity								
4. Combined cycle	-0.3%	-4.5%	0%	1%	0%	1%	0%	5%
5. IGCC	-3.7%	-9.3%	4%	9%	2%	2%	1%	-1%
6. Improved distri- bution	-1.0%	-1.0%					0%	-1%
Non-fossil fuels								
7. Nuclear	-0.4%	-7.1%	1%	5%	0%	1%	0%	-5%
8. Solar /wind	-2.2%	-5.0%	7%	4%	1%	1%	0%	-3%
9. Hydro	-2.4%	-1.9%	-1%	0%	0%	0%	-1%	-2%
10. Biofuels	-0.3%	-2.0%	-1%	-1%	1%	2%	3%	9%
Carbon tax								
11. 30 US\$ per tC	-6.7%	-29.8%	4%	16%	21%	15%	31%	18%

Note: IGCC = Integrated Gasification Combined Cycle; furthermore, numbers cannot be simply added up as they relate to individual model experiments.

solar) to improve their competitive position are unlikely to be very successful. Additional measures are required, such as long-standing renewable energy obligations or a combination of policies to promote non-fossil based alternatives and carbon taxes. The relatively modest policies explored here can reduce emissions by 5–10% for both nuclear and solar/wind power. The contribution of additional hydropower is modest as most of the existing resources are already used in the baselines. Biofuels (as an alternative to natural gas and oil) can reduce emissions to some extent—but will probably need to be imported.

Finally, as indicated earlier, a carbon tax of US\$30 per tonne carbon introduced slowly in the 2015–2030 period induces a set of measures, which combined, reduce emissions by 30% in both scenarios. Such a strategy requires considerable additional investments to be made and increases user costs. As the funds raised by the tax itself can, in principle, be recycled, the net increase of user costs is 10 to 15%. As the carbon tax induces a large shift from coal to oil and natural gas use, the tax increases the fuel import costs by 20–30%.

4.5.3. Combining different measures into mitigation scenarios

The energy system is complex and there is a difference between the effectiveness and costs of a single option/measure in isolation or the same option/measure in combina-

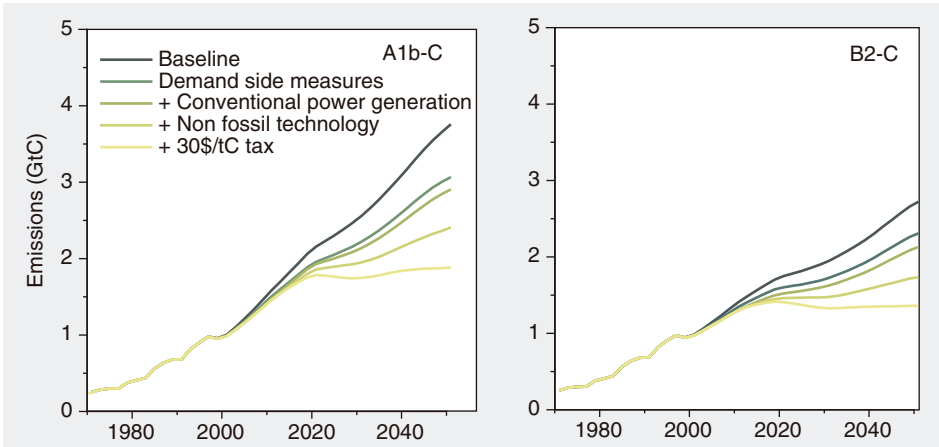


Figure 4.11 Carbon emission reductions achieved by a combination of policy measures.

tion with others. Here, we will present the results of a mitigation scenario based on a combination of the policy options discussed in the previous section. We have grouped them into four different categories: (1) demand-side measures, (2) measures for fossil-based electricity, (3) non-fossil technologies and (4) a carbon tax of US\$30 per tC, fully effective after 2030.

Figure 4.11 (left) shows the carbon emission profile for the sequence of these different options starting from the A1b-C baseline. Demand-side measures form a very important part of the emission reductions obtained in these scenarios. If all options/measures are implemented, emissions are reduced by 50%—leading to a level of 2 GtC in 2050. The type of policies explored should certainly be regarded as feasible. Figure 4.11 (right) shows the same results, but now with the B2-C scenario as the baseline. Here, too, carbon emissions can be reduced by around 50%—and the final emissions come to about 1.3 GtC per year (stabilization after 2020/30). A large potential for GHG emission reduction was also identified in other studies (e.g. Jiang et al., 1998).

4.5.4 Kaya-factor accounting

The results can also be expressed in terms of the so-called Kaya identity. Figure 4.12 shows the changes in carbon emissions for 1970–1995, 1995–2020 and 2020–2045 for the baseline and the combined mitigation scenario (black bars). The stacked bars on the left of the black bars also indicate which factors have contributed to these changes (“Kaya” factors). The figure shows that not only in the mitigation scenario, but also in the baseline scenario, several factors contribute to emission reductions. Between 1970 and 1995, emissions would have increased by a factor of 8, driven by population and economic growth, and a shift towards commercial fuels, if not for a strong improvement in energy efficiency. Taking this improvement into account, the net increase is slightly less than a factor of 4. Reduction of energy intensity—based either on deliberate policies to improve energy efficiency or autonomous changes—will continue in the future to be an important force preventing the Chinese emissions from doubling or

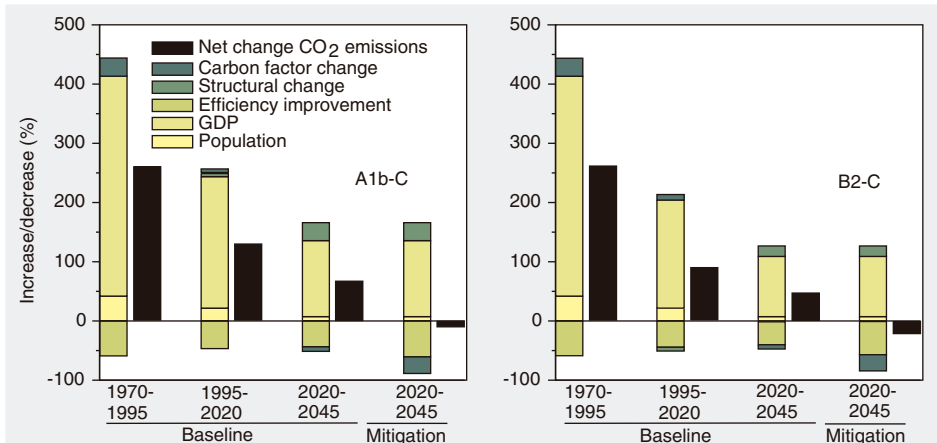


Figure 4.12 Changes in carbon emissions in 25 year periods and allocation of these changes to changes in Kaya factors.

even quadrupling in 25 year periods. Structural change represents overall an upward factor on emissions due to fast growth of the transport sector. Reduction in the carbon factor caused by shifts from coal to natural gas in residential areas also plays an important role in this. The mitigation scenarios push the contribution of these factors considerably further. In both the A1b-C and B2C scenarios, the mitigation scenario is successful in actually stabilizing emissions after 2030.

4.6 Conclusions and suggestions

4.6.1. Conclusions from the scenario analysis

Our scenario analyses suggest a number of trends and options with regard to future GHG emissions in China. Given economic and population growth scenarios, carbon emissions can be expected to increase by a factor of 3–4 in the first half of the century. In absolute terms, the increase will be largest in electric power generation and industrial production. The high growth in electricity demand and the competitive position of Chinese coal in this sector make electricity generation the fastest growing and, from 2015 onwards, largest carbon-emitting activity. Industry is also expected to rely heavily on coal for the first decades of the century, but the increasing market share of oil and gas, in combination with a decline in the energy-intensity of new industries, may well lead to stabilization in industrial carbon emission before 2040. The fastest growth in energy use is in the transport sector; however, it remains rather small in absolute terms and will rely mainly on oil and natural gas with a lower carbon content. Consequently, the sector is one of the driving forces behind rapidly growing oil and gas imports. In the residential and services sector, a phase-out of traditional fuels and, especially in urban regions, of coal, can be expected. Carbon emissions are expected to grow only slowly in these sectors.

Given these trends, China, with coal remaining the dominant energy carrier, will contribute an even larger part to global carbon emissions—becoming the largest emitter in the third decade of the century. The IMAGE 2.2 model indicates that both scenarios are expected to lead to an increase in global temperature of about 3–4°C by the end of the century (IMAGE-team, 2001). China is expected to experience temperature increases similar to this overall global increase.

Longer-term carbon emission trends, in the second half of the century, will be largely determined by—uncertain—developments in the economic and social feasibility of non-carbon options such as solar/wind and biomass-derived fuels. It is also in the longer term that the difference between the various scenarios—in terms of sustainable development orientation, openness to fuel trade and the like—starts to make a large difference. For instance, by 2100 primary energy demand may differ up to a factor of 4 and carbon emissions up to a factor of 8. An important dynamic factor here is the assumed learning-by-doing which induces important cost decreases for non-carbon options as result of R&D and investment programmes in the sustainable development-oriented future. However, our analyses clearly indicate the large benefits of an orientation on sustainable development, especially in the longer term, for both China—lower urban air pollution, for instance—and the world.

Our exploration of emission reduction options suggests a large potential, at costs which are low compared to international standards. Not all options will be equally attractive and feasible across the various scenarios. In the first decades, a strengthening of energy conservation policies is most beneficial and cost-effective. However, energy efficiency improvements are often confronted most with institutional and financial barriers, especially in rapid growth periods in low-income countries.

Under both baselines, coal is expected to remain a dominant fuel in electricity generation. There are several specific measures to reduce GHG emissions in the electric power sector. First of all, introduction of clean coal use techniques (highly efficient IGCC, for instance) and an accelerated substitution away from coal to natural gas (with concomitant rise in gas imports) can be key options in the electricity sector (see also Zhang, 1998). Accelerated expansion of hydropower has only a marginal reduction potential—some 2% by 2050. Other non-fossil fuels, such as nuclear, wind and solar energy can be important for reducing carbon dioxide emissions further, certainly in the longer term. However, in view of the strong competitive position of coal, these fuels can only play an important role when they are supported by a lasting policy-guided effort (e.g. renewable energy obligation targets or carbon taxes). In all cases, the required investment fluxes may pose the largest challenge.

The analyses also show important trade-offs between the different options in terms of investments, increase of user costs and impacts on the balance of trade and emissions. For instance, policies that rely on a fuel switch from coal to oil might be cheap in terms of required investments but increase the costs of fuel imports.

Finally, it was also found that, in view of the differences in costs with Annex-I regions, there could be a considerable potential for CDM projects that could lower some of the financial barriers (see also Li, 2000; Sands and Kejun, 2001).

4.6.2 Suggestions for policy implementation

These policy measures discussed above need to be implemented in the context of existing (environmental) policies and development strategies in China. Below, we will make some suggestions how this could be done based on knowledge of the Chinese situation, international experience and the results of our analysis.

First of all, policy to reduce GHG emissions could be combined with existing plans, in particular, a domestic sustainable development strategy and the national energy development plan. Sustainable development is already recognized as an important factor for both short- and long-term plans. Agenda 21 for China, announced by the Chinese government in 1994, addresses the sustainable path into the future, which covers many energy activities. Policy options assessed in this study, such as clean energy utilization (including natural gas and non-fossil based energy) could well match the targets described in these national plans (Zongxin and Zhihong, 1997).

Secondly, it will be important to focus on non-regret opportunities. Much of the potential emission reductions discussed above can be implemented even with finding benefits larger than costs, certainly when taking into account the co-benefits (reduction of air pollution) (Wang and Smith, 1999). International technology collaboration to respond to climate change could provide an essential basis for developing countries to reach their sustainable development goal, such as CDM and technology transfer (see also Jiang et al., 1999).

In terms of instruments, many options are available. International cooperation could focus on GHG emission reduction and domestic sustainable development, thereby helping to reduce some of the political and financial barriers to GHG mitigation in China. Tax reform in China started 10 years ago: energy subsidies have been reduced and a fuel tax for transport will be established soon. In most OECD countries, energy taxation was originally implemented for revenue considerations. Now that the time period is different, it may be wise for China to consider not only revenue but also environmental concerns in its current tax reforms. Such taxes (either carbon tax or a mixed energy tax) could discourage the use of environmentally harmful energy types and cover so-called externalities. For other issues, a focus on physical planning and performance standards can be more effective than economic instruments.

To conclude, in this chapter we have seen that the emissions of carbon dioxide are expected to grow rapidly under different assumptions for the baseline scenario. The rate of increase is determined by several factors, such as economic growth, energy efficiency but also by the focus on environment and sustainable development values. We have also indicated the potential for emission reduction as being considerable and

often low cost. Most options have important trade-offs between different types of policies in terms of investments, user costs, import costs and environmental effectiveness.

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Appendix 4.1 Major assumptions within the baseline scenarios

	A1b-C	B2-C	A1F	B1
<i>Demand</i>				
Population	In all scenarios, we have assumed population to increase to 1.6 billion in 2050 and afterwards to decrease to 1.5 billion in 2100.			
GDP growth	Very fast (2050: 10230 US\$/cap; 5.3% p.a. 1995-2050)	Strong (2050: 7490 US\$/cap; 4.8% p.a. 1995-2050)	Very fast (2050: 10230 US\$/cap; 5.3% p.a. 1995-2050)	Fast (2050: 10230 US\$/cap; 5.3% p.a. 1995-2050)
Lifestyle	Material – intensive lifestyles (relevant parameter reaches a value of 50% above default)	Moderate trend to dematerialization (relevant parameter reaches a value 10% above default)	Material – intensive lifestyles (relevant parameter reaches a value 50% above default)	Strong dematerialization (relevant parameter reaches a value 20% below default)
Autonomous efficiency improvement	Fast efficiency development, pushed by private investment	Normal efficiency improvement	Fast efficiency development, pushed by private investment	Fast efficiency development, pushed by private investment and technology transfer
Price-induced efficiency improvement (accepted pay-back times)	Accepted pay-back times reach current OECD levels (e.g. 3 years in industry)	In between A1b-C/A1f and B1.	Accepted pay-back times reach current OECD levels (e.g. 3 years in industry)	Accepted pay-back times reach levels of twice current OECD levels (e.g. 6 years in industry)
Fossil fuel resources	In all scenarios, we have assumed extensive fossil fuel resources in China – with both resources and production costs based on Rogner (1997). These resources also cover undiscovered and unconventional types such as methane hydrates and unconventional oil.			
Energy taxes	Energy end-use taxes converge to current USA levels in 2100 (e.g., 4-6 US\$4-6 per GJ in transport)	In 2100, end-use taxes reach a level in between the final B1 level and the current regional level	Energy end-use taxes converge to current USA levels in 2100 (e.g., 4-6 US\$/GJ in transport)	Energy end-use taxes converge to current Western European levels in 2100 (e.g., 14-16 US\$/GJ in transport)
Preference levels for end-use fuels	Strong aversion to use of coal for health, convenience and environmental reasons	Very strong aversion to use of coal for environmental reasons	Modest aversion from use of coal; problems related to coal use are solved differently	Very strong aversion from use of coal for environmental reasons
<i>Electricity</i>				
Efficiency of thermal power	Increases to 0.47-0.49 for coal, 0.51-0.54 for oil and 0.56-0.58 for natural gas	Increases to 0.44-0.48 for coal, 0.49-0.53 for oil and 0.53-0.57 for natural gas	Increases to 0.48-0.50 for coal, 0.52-0.55 for oil and 0.57-0.59 for natural gas	Increases to 0.44-0.48 for coal, 0.49-0.53 for oil and 0.53-0.57 for natural gas
Preference levels for fossil fuels	No preferences or aversion to any fuel in 2100	No preferences or aversion to any fuel in 2100; only small add-on cost for clean coal.	No preferences or aversion for any fuel in 2100	Very strong aversion from use of coal for environmental reasons
Preference levels for types of production	Indifferent	Indifferent	Indifferent	Preference for renewable electricity production; modest aversion towards nuclear; strong aversion towards fossil

<i>Fuel supply</i>				
Technology development for fossil fuels	Default (0.90)	Default (0.90)	Fast (0.87)	Default (0.90)
Technology development for renewables	Strong till 2040 (around 0.8-0.87), default from 2040 onwards (0.90)	Strong till 2040 (around 0.8-0.87), default from 2040-2060, 2060-2100 slower (0.92)	Slow to very slow (0.92-0.95)	Strong till 2040 (around 0.8-0.87), modestly strong from 2040 onwards (0.88-0.90)
Trade	No trade constraints	Trade between global regions is limited	No trade constraints	No trade constraints

Appendix 4.2 Translation of the policy options into system variables

This annex indicates how the policy options discussed in the main text have been translated into changes in model parameters.

Policy option/measure	Implementation explored in modelling experiment	Changes in model parameters
1. Incentives for energy-efficiency investments:	Reducing the gap in final energy intensity between Western Europe and China in 2050 by another 30% beyond the baseline.	Increase the accepted payback time for energy efficiency investments in such a way that the required energy intensity is reached
2. Energy taxation inducing a series of responses	Adding an energy tax –equal for all fuel types – for industry and transport equal to current Western European tax levels for oil and gas.	Increase the tax on fuels in these sectors to reach the Western European level by 2020.
3. Influencing market penetration of secondary energy carriers	Reducing the use of coal in the building sector to zero.	Introduce a premium factor for coal to phase coal out of the residential and service sector by 2020, for example.
4. High-efficiency, gas-fired Combined-Cycle (CC) in central electric power generation	In 2050, 15-20% of all electricity is generated by gas-fired combined cycle	Change the premium factor for natural gas for electricity generation and change its efficiency.
5. Advanced Clean Coal (ACC) option, including Integrated Gasification Combined Cycle	All new coal power plants from 2010 onwards are highly efficient.	Change efficiency of coal power plants.
6. Reducing transmission losses	Losses in distribution and transmission of electricity are reduced in 2050 to the level of OECD countries (8%).	Change distribution and transmission losses
7. Increasing the share of nuclear power generation	Use of nuclear power is increased from 10% (A1b-C) and 7% (B2-C) to 20% of all electricity generated.	Forced expansion
8. Increasing the share of renewables such as solar and wind in electric power	Use of new renewables in electric power generation is increased from 7% (both A1b-C and B2-C) to 20% of all electricity generated. In 2020, the required share is 10%.	forced expansion.
9. Increasing the share of hydropower generation	Use of hydropower is increased from 68% to 90% of maximum implementable potential.of 378 GW.	Accelerate hydropower by forced expansion as to reach 350 GWe installed capacity by 2050.
10. Accelerating the penetration of biomass-derived fuels	Overrule market dynamics with expansion targets; 10% market share in oil/gas market 2020, 20% market share in 2050.	Forced expansion.
11. Carbon taxation inducing a series of responses	Implementation of a US\$30 carbon tax.	Implementation of a US\$30 carbon tax, slowly building up from 2020 onwards.