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Energy and emission scenarios for China in the 21st century
Exploration of baseline development and mitigation options

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Abstract

The purpose of this study was to explore possible baseline developments and available options for mitigating energy-use related emissions in China. The first part of the report deals with an analysis and overview of available data on historic energy production and consumption trends and current energy resources. Special attention was paid to the 1995-2000 period, in which the trend of Chinese carbon dioxide emissions seems to have temporarily reversed. The major part of the project focused at developing a set of energy and emission scenarios for China for the 1995-2100 period on the basis of the global IPCC baseline scenarios, with the use of the simulation model IMAGE/TIMER. The two main baseline scenarios of the study differed, among other aspects, in the openness of the Chinese economy and in economic growth. However, both indicate a rapid growth in carbon emissions (2.0 and 2.6% per year in the 2000-2050 period). The baseline scenario analysis showed that an orientation on environmental sustainability may not only reduce other environmental pressures but also carbon dioxide emissions. In the mitigation analysis, a large number of options were evaluated in terms of impacts on investments, user costs, fuel imports costs and emissions. A large potential was found to exist for mitigating carbon dioxide emissions in China, for example, in the form of energy efficiency improvement (with large co-benefits) and through measures in the electricity sector. Combining all options considered would appear to offer a possibility for reducing emissions by 50% in comparison to the baseline scenarios.

Contents

Samenvatting

In dit onderzoeksproject zijn met behulp van het simulatiemodel IMAGE/TIMER enkele lange termijn energie- en emissiescenario's voor China ontwikkeld (1995-2100). Het doel van de studie was het verkennen van mogelijke baseline ontwikkelingen en van beschikbare opties voor het reduceren van emissies.

Om allereerst een goed beeld te krijgen van de huidige situatie in China en het IMAGE/TIMER model aan te passen aan specifieke informatie over China is eerst een overzicht gemaakt van relevante informatie over energieproductie en –verbruik tussen 1980 en 2000. Speciale aandacht is besteed aan de periode 1995-2000, omdat in deze periode volgens beschikbare gegevens de Chinese emissies zijn gedaald. Ook is gekeken naar energievoorraden in China.

De ontwikkelde scenario's zijn gebaseerd op de IPCC SRES scenario's, zoals uitgewerkt voor de wereld in het IMAGE 2.2 model. Deze scenario's zijn echter nader ingevuld op basis van data en expert judgement over mogelijke ontwikkelingen van Chinese experts. De twee belangrijkste baseline scenario's van de studie verschillen met name in de openheid van de Chinese economie en in het niveau van economische groei, hoewel beide een snelle groei van CO_2-emissies laten zien (2.0% en 2.6% per jaar in de periode 2000-2050). Een alternatief baseline scenario laat zien dat een oriëntatie op duurzaamheid (met accent op milieu) het mogelijk maakt niet alleen regionale luchtverontreiniging te verminderen maar tevens de CO_2-emissies terug te brengen.

In de analyse van de reductiemogelijkheden is een elftal opties geëvalueerd in termen van impact op investeringen, kosten voor de gebruikers van energie, brandstof-importkosten en vanzelfsprekend op het niveau van de emissies. Deze analyse liet zien dat er een groot potentieel is om de CO_2-emissies in China te verminderen door middel van vrij beperkte maatregelen (maatregelen die vooral zijn gebaseerd op het huidige beleid in West Europa). Hieronder vallen onder meer het verbeteren van de energie-efficiëntie en maatregelen in de elektriciteitssector. Door alle opties te combineren lijkt het mogelijk om emissies in 2050 in vergelijking met de baseline scenario's met 50% te reduceren. Een deel van de maatregelen heeft positieve neveneffecten in de vorm van emissiereductie van andere stoffen of vermindering van importkosten van brandstoffen. Andere maatregelen leiden juist tot een sterke toename van importkosten.

Summary

Several baseline and policy scenarios have been developed to explore the possible development of the energy system in China and the associated environmental pressure, the uncertainties involved and the potential for carbon dioxide mitigation.

Baseline scenarios

The two baseline scenarios developed in this project are based on the IPCC special report on emission scenarios (SRES). The first scenario describes an '*open China in a globalised world'* (referred to as the A1b-C scenario). The most important assumptions in this scenario are rapid economic development of China and the world, rapid technological advances, free trade, including trade in energy resources, and technology transfer. The second scenario describes an alternative image of a '*China geared to solving regional environmental problems'* (referred to as the B2-C scenario). The most important assumptions in this scenario are a stronger orientation towards development of the local economy while protecting the local environment, and constraints on trade and technology transfer, as a result of which China will use more domestic energy resources (in particular based on clean-coal technologies). The TIMER/IMAGE integrated assessment model was used to quantify these scenarios. The results are presented below.

1. Without climate-change policies, energy consumption and greenhouse gas emissions in China are likely to increase sharply. The A1b-C and B2-C baselines show an increase in emissions between 1995 and 2050 by a factor of 4 and 3 respectively. Energy use in transport is expected to increase most rapidly, particularly in the A1b-C scenario.
2. In the A1b-C scenario, China's GDP is assumed to reach a level of US$16.94 trillion (1995 US$, hereafter the same) in 2050, about 16 times the GDP in 2000. As a result, primary energy consumption is expected to increase to 7300 Mton ce. The share of oil and natural gas will by that time have increased to 36%, mainly based on imports. The share of coal will decline to 42%, while nuclear and renewable energy will account for 22%. The total net energy imports are expected to be 1300 Mton ce, costing a total of US$410 billion. CO_2 emissions will increase to3760 Mton C, while SO_2 emissions in fact decline to 12 Mton.
3. In the B2-C scenario, China's GDP is assumed to reach US$12.33 trillion in 2050, about 12 times the GDP in 2000. The increase in primary energy consumption is somewhat slower than in the A1b-C scenario (5000 Mton ce in 2050). The energy mi in 2050 is projected to be 53.4% coal, 28.8% oil and natural gas and 17.8% nuclear and renewable energy. Net energy imports are significantly lower than in A1b-C (490 Mton ce or US$210 billion). CO_2 emissions increase to 2720 Mton C and SO_2 emissions decline to about 7Mton.
4. The level of investment required, in particular in thermal power plants in the first half of the century is expected to increase sharply - calling for sufficient allocation in China's development budget. Investments are expected to be in the order of US$500-1000 billion per year in 2050; by comparison, the current investments in Western Europe are in the order of US$130 billion
5. In the baseline scenarios, energy-related carbon emissions in China between 2000 and 2050 will come mainly from coal use in electricity and industry. The key to reducing China's carbon emissions lies in these two sectors.

6. A focus on environmental sustainability (e.g. urban air pollution; regional air pollution), as assumed in the B2-C and B1-C scenarios could not only reduce environmental pressures but also result in lower carbon dioxide emissions
7. None of the baseline scenarios (including our assumptions for other parts of the world) will meet the targets set out by the UNFCCC ('stabilisation of greenhouse gas concentrations at levels that prevent dangerous anthropogenic interference with the world's climate system'), so climate policies will be needed.

Separate measures and instruments
To get a better idea of the potential impact of different policies in China, we have concluded a series of modelling experiments in which the impacts of eleven mitigation measures and instruments was separately explored within the context of the two baseline scenarios.

The results are:
Relatively low cost measures, in relation to international standards, could induce an effective reduction of carbon dioxide emissions. Such measures are based on energy-efficiency improvement and switches from carbon-intensive energy to less-intensive or zero-emission energy.

- Enhancing policies for energy conservation and improving energy utilisation efficiency (aimed at reducing the gap in energy intensity between China and Western Europe by an additional 30% in 2050) could reduce the energy intensity from 2.3 tce / US$1000 in 1995 to 0.32 tce / US$1000 in 2050. This measure will raise user costs but will reduce energy demand and imports. Carbon dioxide emissions would be reduced by 11% (A1b-C) and 14% (B2-C) respectively in 2050.
- If a carbon tax is introduced from 2015 onwards, reaching a level of US$30 t C in 2030 and then remaining constant, compared with the baseline of the A1b-C scenario, carbon dioxide emissions could be reduced by 31% in 2050. Revenues from a carbon tax would be US$ 57 billion, which is close to the additional investment in energy (US$ 63 billion). At the same time, additional payments for imports will be US$ 80 billion (due to a shift from coal to oil and natural gas). Compared with the baseline of the B2-C scenario, carbon dioxide emissions could be reduced by 30$ in 2050. Revenues from the carbon tax will be US$ 79 billion while additional investments in energy will reach US$ 146 billion. At the same time, additional payments for imports will be US$ 80 billion.
- Our scenarios indicate a strong increase in electricity use in China in the coming decades. Under baseline conditions, coal is expected to remain a dominant fuel in electricity generation given its very low costs and the large domestic resources. There are several specific measures that could reduce carbon dioxide emissions in the electric power sector in China.
- One measure is to use more natural gas. Increasing the share of natural gas-fired combined cycle power plants to 15% of total capacity in 2050 could bring about a reduction of 3% in the carbon emission in 2050. However, increasing natural gas leads to more imports.
- Alternatively, coal use could be based on highly efficient IGCC (integrated gasification combined cycle). Carbon dioxide emissions could be reduced by 9% in both scenarios. In the B2-C scenario, this will require a capacity of 1200 GW of IGCC in 2050 and an additional cumulative investment in energy of US$ 275 billion. In the A1b-C scenario both numbers are somewhat higher.
- Ambitious hydropower expansion (350 GW installed capacity in 2050) could bring about a 2% reduction in carbon emissions in 2050. However, since hydropower would be

approaching its maximum potential in such a case, it will be of limited relevance for carbon reduction in the second half of the century.

- Other non-fossil energy sources, such as nuclear, wind and solar energy will be very important to reduce carbon dioxide emissions even further. These new energy sources will slowly become more competitive. However, as electricity in China can be cheaply produced from large coal resources, these options can only play an important role in reducing emissions if they are supported by a long-term policy-guided effort (renewable energy obligations targets or carbon taxes).
- For several reasons, including environmental protection and convenience in handling, it is attractive to strongly phase out coal use in the residential, commercial and transport sectors by 2020. In fact, such a phase out was assumed to partly take place already in our baselines. This emphasises the co-benefits to climate change mitigation from environmental polices (and by the same token the other way around).
- Other effective measures could be 1) gradually increase end use energy tax to the level of Western Europe in 2050, 2) reduce losses in distribution and transmission of electricity, 3) increase the share of biomass in the oil and gas market.
- The analysis of the various options shows important trade-offs between different types of policies in terms of investments, increase of user costs, impacts on trade balance, carbon dioxide emissions and other emissions. In particular, policies that rely on a fuel switch from coal to oil and natural gas might be relatively cheap in terms of overall energy costs, but will increase the costs of fuel imports. Such policies include energy taxation, more use of natural gas in combined cycle power plants and carbon taxes. Energy-efficiency measures, for their part, reduce the costs of fuel imports.

Combining 11 options into mitigation scenarios

If all policies (grouped into four different categories) are combined and implemented, carbon dioxide emission in China can be reduced by 50% in 2050 compared with the baseline scenarios. Total primary energy consumption and carbon dioxide emissions will decline to 4900 Mton ce and 2 GtC respectively in the A1b-C scenario and to 3400 Mton ce and 1.3 GtC in the B2-C scenario. It should be noted that the overall carbon dioxide emission reduction from the joint implementation of the 11 policies is less than the sum of the reduction from the implementation of the 11 individual policies, because some policies have similar effects.

The simulation also shows that the costs of reducing carbon emissions in China are considerably lower than in many industrialised countries. For instance, n 2010 at a carbon price of around US$50 / tC, the potential for mitigation in China is 0.2-0.3 GtC. To reduce the same amount in Western Europe, the price will be much higher. Therefore, there could be a considerable potential for emission trading or clean development mechanism (CDM) projects in China.

‘Optimal policies’ in terms of carbon dioxide emissions might, in an early stage, focus more on energy efficiency and fuel switches among the different types of fossil fuels; however, later in the century non-fossil energy sources should produce the greatest reductions.

1. Introduction

Recent publications of the IPCC have shown even more clearly than before that climate change could be a very serious environmental problem in the 21st century (IPCC, 2001). This conclusion is, first of all, based on accumulating evidence that an increase of concentration of greenhouse gases in the atmosphere leads to warming of the atmosphere. In addition, baseline scenarios as published in the Special Report on Emission Scenarios (Nakicenovic et al., 2000) show that human emissions of these greenhouse gasses are expected to increase (significantly) if no action is taken to mitigate them. This leads to the expectation that the global average temperature under baseline conditions could increase by 1.5 to 5.5 degrees Celsius over its current value. Considerable emission reductions, in time in all countries of the world, will be required to prevent this.

The per capita emissions of China are still much lower than the average in OECD countries. At the same time, however, China emits about 10% of the world's carbon dioxide emissions, ranking China among the largest producers of greenhouse gas emissions. Moreover, 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), on the other its primary energy consumption has more than doubled (Zhang, 2001). Greenhouse gas (GHG) emissions have increased at a similar rate. There are indications that China could become the world's largest carbon dioxide emitting country somewhere in the first half of the 21st century. In view of this, there has been considerable attention to potential development of Chinese emissions from both scientists and policy-makers. Despite the fact that China currently still has no obligations to limit its emissions, it does seem very relevant 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?

The project 'Policy Options for CO_2 Emission Mitigation in China' was approved by the Chinese Council on International Collaboration of Environment Development (CCICED), supported by the Dutch Government to study such questions. Under the project, there are four sub-projects, both studying historic changes and future options. This report provides the results of sub-project 6.3. The major task in this sub-project is to explore different possible emissions scenarios and emission reduction options through the application of various scenarios.

In the present report we present the results of the analyses done in co-operation by researchers of the Dutch National Institute of Public Health and the Environment (RIVM) and the Chinese Energy Research Institute (ERI). These two institutes have used the energy submodel of the IMAGE-model, TIMER, to develop a set of newly developed storyline-based scenarios. TIMER was used in order: 1) to evaluate energy-related developments in China in the period 1970-2000; 2) to construct of energy and emission mitigation scenarios up to the year 2050 or 2100 against the background of the new IPCC-scenarios and; 3) to explore some of the options available to China to mitigate emissions.

The report has been organised as follows:

- First, we discuss the current situation and recent trends with regard to relevant economic and demographic changes and energy use in China;
- Next, we give a brief overview of the new set of IPCC emissions scenarios and their relevance for China and describe scenario assumptions for an application of these scenarios for China;
- Finally, we give a more detailed discussion of possible energy and emission futures and mitigation policies in China.

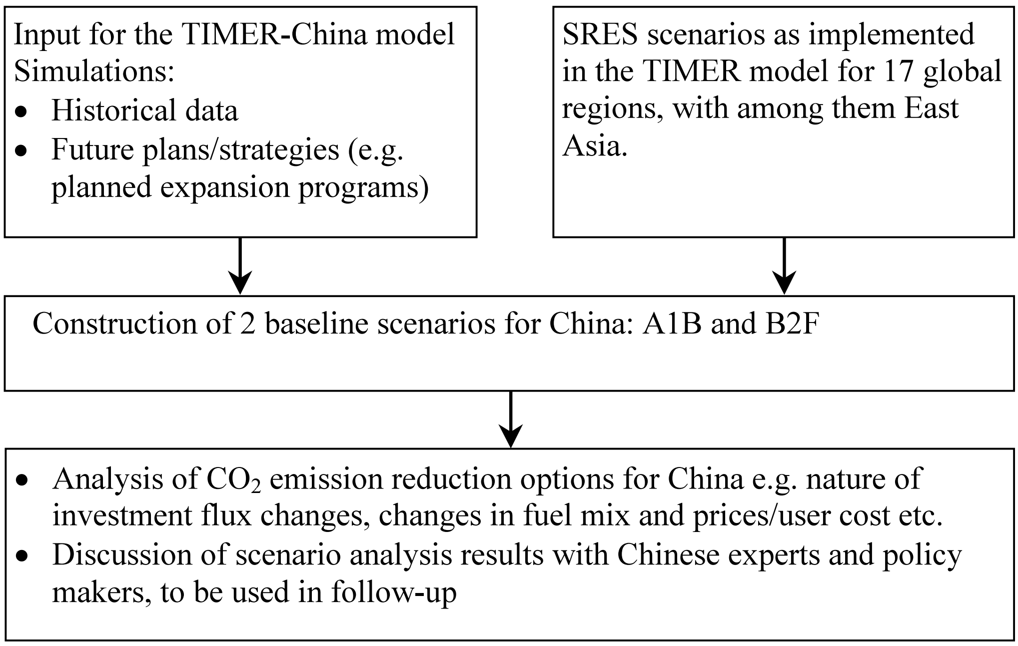


Figure 1.1: General project set-up

2. The TIMER/IMAGE model

In this chapter, we will shortly discuss the TIMER energy model that is used in this report. TIMER is the energy (sub)model of the global environmental change model IMAGE 2.2[1]. An extensive description of the model can be found in De Vries et al., (2001). More information on IMAGE 2.2 can be found in IMAGE team (2001). The TIMER model can be used both integrated within the total IMAGE framework and as a stand-alone model.

IMAGE 2.2 has been developed to study the long-term dynamics of global environmental change, in particular changes related to climate change. It consists of a large set of sub-models that cover the cause-effect chain of climate change (Figure 2.1). First of all, two separate (sub)models describe changes in the population and the world economy. These provide the driving forces for the energy submodel TIMER and the land use model. Both are linked to emission submodels – and information on emissions is fed into the atmospheric chemistry model and the model on the carbon cycle. The Climate model in the next step determines possible changes in the climate system. Finally, several impacts are calculated – such as sea level rise. Between all models various feed-back loops exists.

The main objectives of TIMER are to analyse the long-term dynamics of energy conservation and the transition to non-fossil fuels within an integrated modelling framework, and to calculate energy-related greenhouse gas emissions. The model builds upon several sectoral system dynamics energy models. The current model version presented in this report is implemented for 17 world regions that are shown in Figure 2.2[2]. The model has been carefully calibrated to reproduce the major world energy trends in the period 1971-1995.

It is important to realise that TIMER is not an optimisation model but a simulation model: it does not optimise scenario results over a complete modelling period 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 behaviour, fuel substitution and technology. The output is a rather detailed picture of how energy demand, fuel costs and competing supply technologies develop over time in the different regions. Many of the macro-economic models that are currently often used to develop greenhouse gas emission scenarios deal with the same developments in the form of one or a few highly aggregated production functions and a single backstop technology that supplies non-fossil energy at a fixed cost level. In our view, the two approaches are complementary: the macro-economic models provide consistent links with the rest of the economy, the TIMER-model gives bottom-up process and system insights.

[1] The model is called Targets IMage Energy Regional model (TIMER) because it has been partly developed as part of the IMAGE 2.1 model (Alcamo et al., 1998) and the TARGETS model.
[2] Within the IMAGE 2.2 modelling framework a total of 19 global regions are the basis of analysis. For energy use, however, the regions Antarctica and Greenland can be neglected so that a set of 17 regions remains.

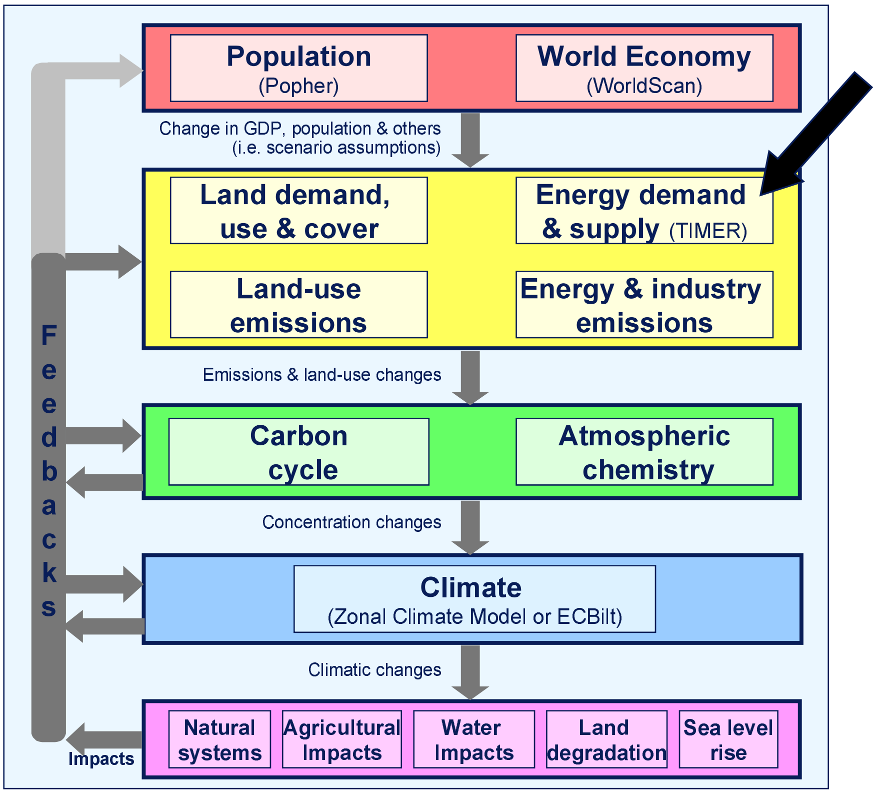


Figure 2.1: Overview of the IMAGE 2.2 modelling framework

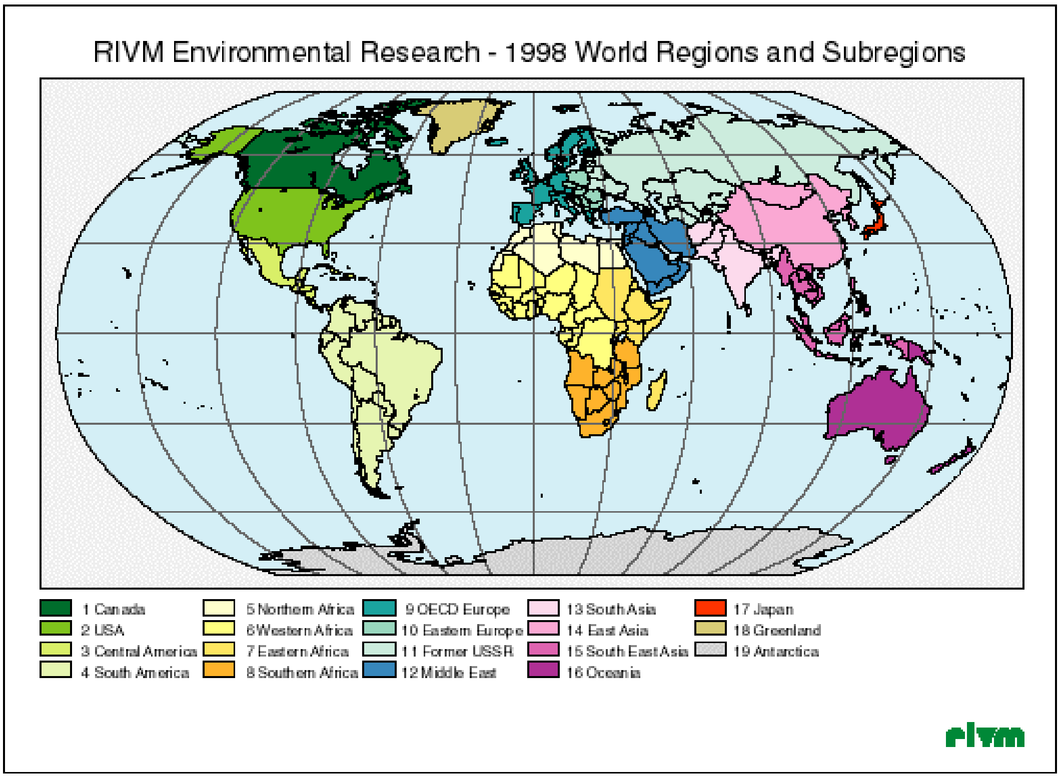


Figure 2.2: IMAGE 2.2 Regions

The TIMER model includes the following main features:

- activity-related demand for useful energy (2 functions: non-electricity and electricity) in 5 sectors, incorporating structural [economic] change due to inter- and intra-sectoral shifts;
- autonomous and price-induced changes in energy-intensity, covering what is referred to as energy conservation, energy efficiency improvement or energy productivity increase;
- fossil fuel exploration and exploitation, including the dynamics of depletion and learning;
- biomass-derived substitutes for oil and gas, penetrating the market based on relative costs and learning;
- electric power generation in thermal power plants and in alternative options (nuclear, wind, solar), penetrating the market based on relative costs and learning;
- trade of fossil fuels and biofuels between the 17 world regions.

The model consists of 5 submodels (Figure 2.3), which are described briefly in the remainder of this chapter.

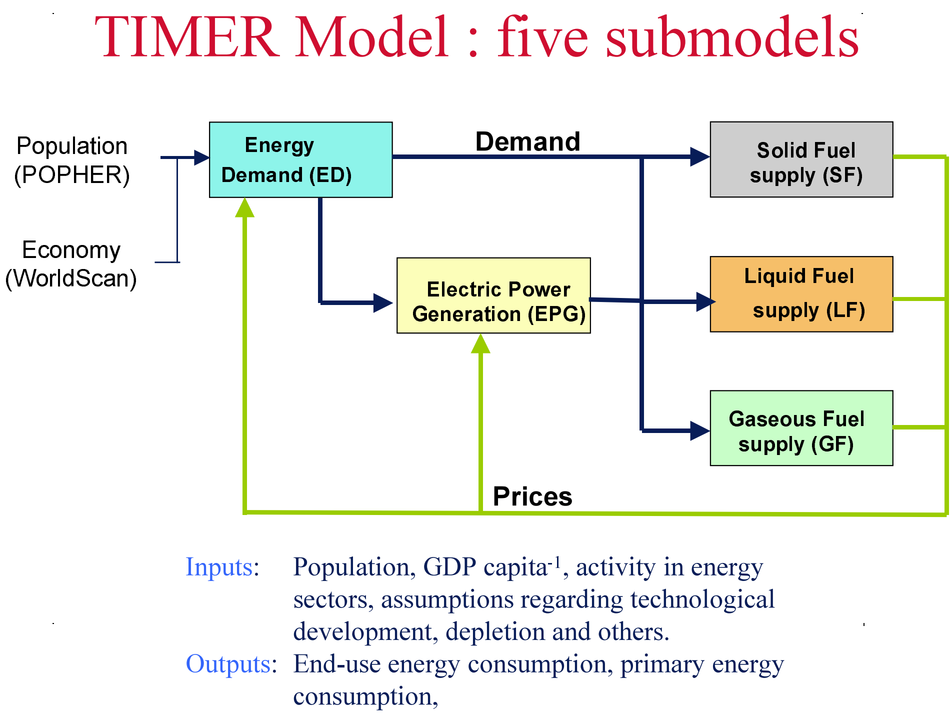


Figure 2.3 Overview of the five submodels of the TIMER-model.

The Energy Demand (ED) submodel

In the Energy Demand model, the demand for final energy is modelled as a function of changes in population, economic activity and energy efficiency improvement. The energy demand is calculated for five different sectors: residential (or households), industrial, commercial (or services), transport and others, and five different types of energy carriers: solid, liquid and gaseous fuels, traditional biomass and electricity. Changes in population and economic activity levels drive the demand for energy services. The calculated demand for useful energy is first multiplied by the Autonomous Energy Efficiency Increase (AEEI) multiplier which accounts for the historical fact that, even with falling energy prices, energy intensity has dropped in most sectors. This multiplier is assumed to decline exponentially to some lower bound and is linked to the turnover rate of sectoral capital stocks. The resulting useful energy demand is then multiplied by the Price Induced Energy Efficiency Improvement (PIEEI) to include the effect of rising energy costs for consumers. This is calculated from a sectoral energy conservation supply cost curve and end-use energy costs. It is assumed that the supply cost curve declines over time as a consequence of innovations from cumulated experiences. Next, the demand for energy carriers is determined on the basis of their relative prices.

The Electric Power Generation (EPG) submodel
The Electric Power Generation (EPG) submodel simulates investments into various form of electricity production in response to electricity demand. Within the model, four electricity producing capital stocks exist: hydropower, thermal, nuclear and other renewables (the latter two are mostly referred to as non-thermal electric energy)[3]. Expansion of hydropower capacity is based on an exogenous scenario. The remaining electricity demand is either fulfilled by the thermal electric stock or the non-thermal electric options (NTE). The penetration dynamics of NTE-technology is based on the difference in generation costs between thermal and non-thermal options using a multinomial logit function. Within the thermal electric stock several fuels can be used. Also their allocation is based on corresponding generation costs. For all investments a certain construction time is assumed before operation starts.

The Fossil Fuel (FF) submodels
The three fossil fuel submodels, solid, liquid and gaseous, have several aspects in common. In all of them, a fossil fuel resource base is explored and exploited. The exploration and exploitation dynamics are governed by a depletion-multiplier and a learning-parameter. The former reflects the rising cost of discovering and exploiting occurrences when cumulated production increases. The latter works to the contrary by assuming that the capital-output ratio will decline with increasing cumulated production due to learning-by-doing in the form of technical progress. An important element in the liquid and gaseous fuel model is the possibility of a non-carbon based alternative fuel penetrating the market. This alternative is confined at present to a biomass-derived liquid/gaseous fuel alternative, for which land will be an important input. Other conversion routes, e.g. coal liquefaction or hydrogen from biomass or solar electricity, have as yet not explicitly been modelled. All three models contain a trade module that simulates interregional fuel trade on the basis of relative price differences and transport cost.

[3] The term Non-Thermal Electric (NTE) is not completely correct as far as nuclear (and also geothermal) heat usually are based on a Rankine-cycle.

3. Current status of social and economic development

3.1 Population and urbanisation

China's population is the largest in the world and it has grown strongly over the last century. In response to the prospect of rapidly increasing demands for all kinds of resources, the government of China has established several policies to control population growth. As a result, fertility rates have dropped strongly and also population growth rates has been steadily decreasing, to a level of less than 1% in 1998 (see table 3.1). It is expected that in the near future this trend will continue (see also Chapter 5 and 6).

Table 3.1: Chinese population between 1970-1998

	1970	1975	1980	1985	1990	1995	1998
Population by the end of the year (10000)	82162	91769	98799	105851	114333	121121	124810
Of which: Urban (%)				23.7	26.4	29.0	30.4
Rural (%)				76.3	73.6	71.0	69.6
Birth rate (%)				2.10	2.11	1.71	1.60
Death rate (%)				0.68	0.67	0.66	0.65
Natural growth rate (%)	2.50	1.72	1.35	1.43	1.44	1.06	0.95

Source: 1999 China Statistical Yearbook; before 1985 based on UN population data

The majority of the population lives in rural areas. However, along with the industrialisation, urbanisation also takes place: the urban population accounted for 26.4% in 1990, and it increased to 30.4% in 1998. This increase could have been larger, but policies are applied that try to limit large migration flows from the rural to the urban areas to allow for a balanced development of the capacity within cities.

3.2 Economic development

3.2.1 National income

China has experienced a very rapid economic development for already several decades in a row. According to the data of the National Bureau of Statistics, during the last 50 years in the 20th century, the average GDP growth rate was 7.7%. The growth rate since the late 1970s (see Figure 3.1) has even been slightly higher[4]. The China's GDP was 8191.1 billion yuan in 1999 and it is estimated that the GDP will be over 8700 billion yuan in 2000, according to the current currency exchange rate, which will be over US $ 1000 billion. This means that in terms of its GDP, China is now is after the US, Japan, Germany, France, UK, and Italy, the 7th largest economy in the world. Income per capita, however, is still less than 1000 US$/capita. China's average per capita income is 578 US$1995 in 1995.

[4] Historic growth rates for China (and many other countries) are subject to uncertainty, as a result of for instance the size of non-monetarised sectors, inflation rates and different accounting methods. Maddison (1997), for instance, found growth rates for China, which are somewhat below the official estimates, i.e. 7.4% versus 9.8% for the 1978-1994 period. Both growth rates are still very high according to international standards.

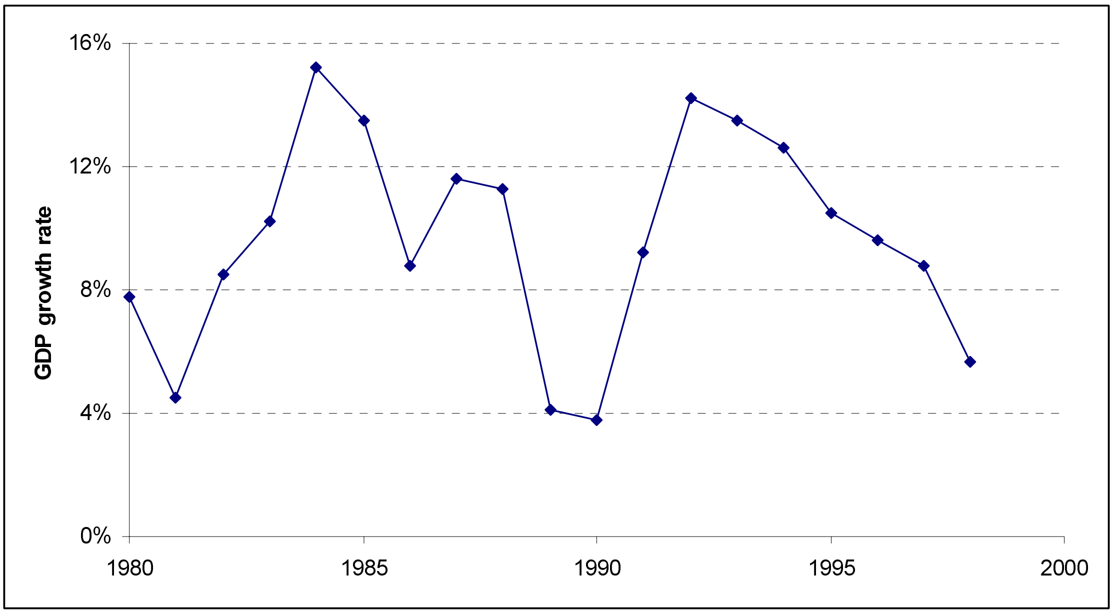


Figure 3.1 China's GDP growth rate from 1980 to 1998

3.2.2 Economic structure

Between 1950 and 1998, China's economy not only grew rapidly, its structure also changed considerable. In 1952, China was still mainly an agricultural based economy with about half of the national income generated in the primary sector. During 1952~1978, China's economic growth heavily relied on industrial development, especially growth of heavy industries. While the average annual GDP growth rate was 6.1% during this period, the growth rate of the industry was as high as 11.4%. As a result by 1978, the industrial sector was by far the most important component of the national economy. In the following period (since the reform of policy and opening), China has been paying much attention to the development of agriculture, light industry and tertiary industry. In particular the service sector, in this period, grew faster than the economy as a whole – increasing the share of the service sector in the total value-added to 33% by 1998.

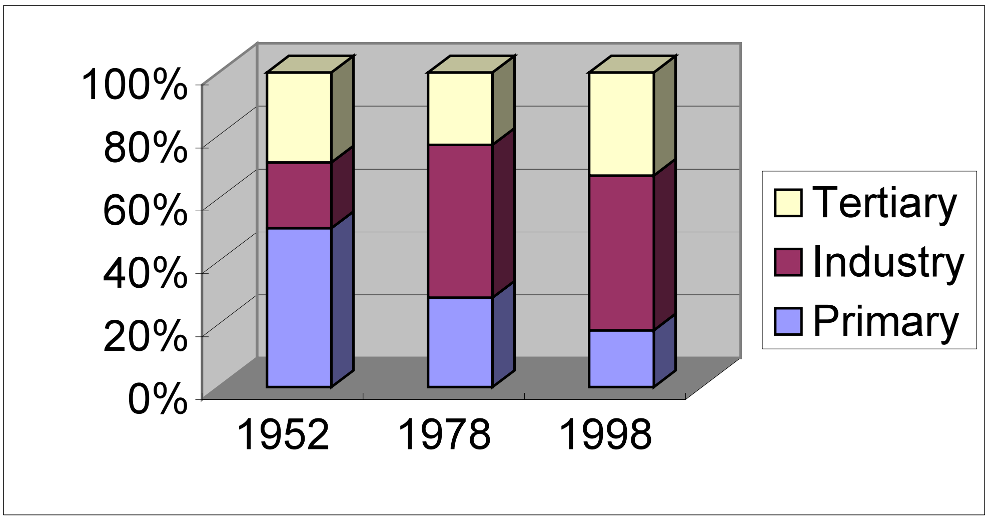


Figure 3.2 Industry structure of China in different years

3.2.3 Confluence into the world economic system

The world has seen a trend of economic globalisation for several years now. One measure for this is the ratio of foreign trading volume to GDP, which increased strongly for most countries. Also China's policies aim to become more and more part of the world economic system. In 2000, China's foreign trading volume was over US$400 billion, or close to 40% compared to total GDP. It shows that the relationship between China's economy and the outside world is more and more narrow. Investment, domestic demand and export are the most important driving forces for economic development in China.

In addition, the foreign currency reservoir of China is over $130 billion, which proved to be a doubling compared to the level of 1995, ranking as the second country in the world. Actual foreign capital utilisation will be over $280 billion during the 9th Five-year period. China has become the second largest country in terms of foreign capital utilisation and in addition the quality of foreign capital improved. It is believed that China will become one of the important members of the world economic system along with the entry to the WTO.

3.2.4 Per capita income

In China there are considerable differences between the average income in rural areas and urban areas. Per capita net income of rural residents within China increased from 134 yuan in 1978 to 2210 yuan in 1999, increasing 4.7 times by comparable price, meaning an average annual increase rate of 7.7%. Per capita controllable income of urban residents increased from 343 yuan in 1978 to 5854 yuan in 1999, increasing 3.6 times (by comparable price) with an average annual increase rate of 6.3%. The per capita consumption in China as a whole increased from 184 yuan in 1978 to 3143 yuan in 1999.

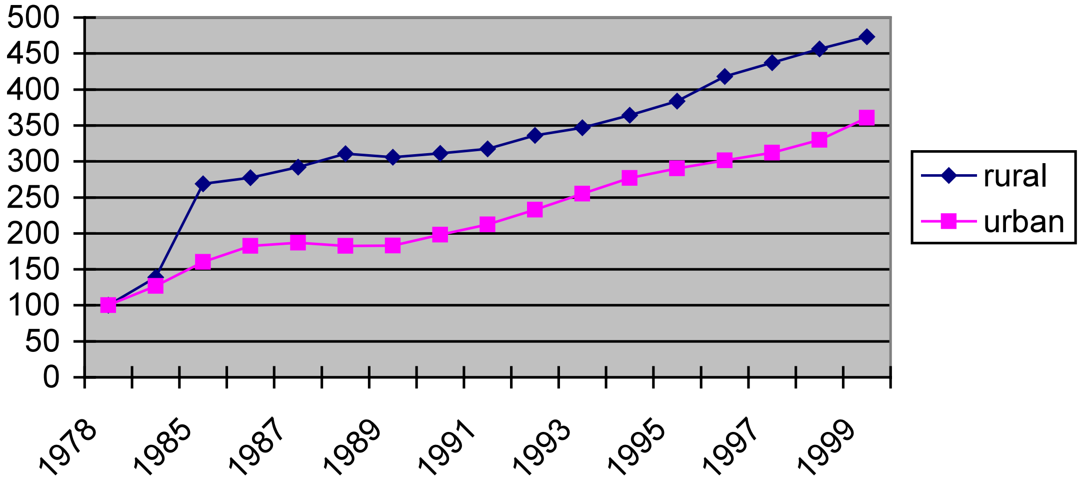


Figure 3.3 Per capita income increase trend in China (1978=100)

4. Current status of energy development in China

In this chapter we present a brief overview of estimates and insights about the current energy resources in China and trends in consumption and production of energy. Our discussion is based on various Chinese and non-Chinese evaluations, some of which – notably IEA and Rogner (1997) – have also been used for the TIMER SRES scenarios. Throughout this chapter, we face the difficulty of different aggregations in the various energy-related analyses. In the project the focus is on the People's Republic of China for which the National Statistical Bureau of China is the most important data source. In the IMAGE 2.2 model, China is part of the region East Asia (region 14) which also contains Hong Kong, Democratic People's Republic of Korea, Republic of South Korea, Macao, Mongolia and Taiwan. Rogner (1997) uses the IIASA classification according to which China is part of the regional group CPA (Centrally Planned Asia and China) which includes also Cambodia, Hong Kong, Lao (PDR), Vietnam, Korea (DPR) and Mongolia. We will try to desaggregate the figures to the level of China as far as possible.

Another issue is the definition of certain energy flows and resources. For instance, according to the energy statistical system in China, transport for several end-use sectors are included under the header of those specific sectors. In contrast, in the internationally used statistics, e.g. from the International Energy Agency (IEA), this type of energy use is headed under transport. Therefor careful interpretation is required. To be consistent with the international statistical system, we adjusted the energy consumption of transportation, mainly moving a certain percentage of diesel oil and gasoline from industry, services and other sector to transportation based on some expert judgement.

Wherever possible, we have attempted to assess the data quality by comparison of different sources.

4.1 Energy resources: introduction

Resource estimates are often reported in various different forms. It is therefore important to notice the distinction between them clearly. To start, the term reserve refers to occurrences that are known and considered to be potentially exploitable. Resources are estimates of total occurrences. In the TIMER model, the information that is actually used is the long-term supply cost curve. That is, the expected increase in costs to produce 1 GJ of energy output, due to depletion of the resource base with constant (1995) technology. Such a curve is highly speculative as it has to be inferred from scarce information on intermediate variables such as coal seam thickness and depth, resource quality, associated gas occurrences, need for secondary and tertiary production techniques etc.

4.1.1 Coal resources

According to the third national coal resources prediction and evaluation completed in 1997, China's total coal resources within the depth of 2000m are 117 ZJ (5.57 trillion tons) and those within the depth of 1000m are 60 ZJ (2.86 trillion tons). Obviously, the proven reserves are smaller. By the end of 1995, China's proved coal reserves were 13 ZJ (604.4 Gt). In accordance with the definition of the World Energy Commission, recoverable proved reserves (proved amount in place) were 2.4 ZJ (114.5 Gt), accounting for 11.0% of the total reserves in the world.

Out of the total coal reserves, 75% are bituminous coal, 12% are anthracite coal, and 13% are lignite. About the purpose of use, 17% are suitable for coke making and gas production and 83% are steam coal. Out of steam coal, 46% and 38% is mainly distributed in the North of China and in Northwest China respectively. The average sulphur content in steam coal is 1.15% and the average ash content is 16.84%.

Of the coal reserves only about 7% of the total quantity in China is suitable for open cast mining. From this part of the coal reserves, 70% is lignite. China has rich coal bed gas resources as its richest coal resources. It is estimated that the total coal bed gas resources existent in the fields that are less deep than 2000 meters is about 30-35 tera cubic meters. Coal bed gas resources concentrates in the eastern area of Mt. Lvliang of North China, with the E'erduosi Basin, the Zhunge'er Basin and the Tu-Ha Fields, which resources accounts for about 85% of the total.

The Chinese national estimates do not comply with the estimates of Rogner (1997). Rogner indicates that China's coal resources are relatively large and contain some 50 ZJ hard coal and 3.2 ZJ brown coal if all categories: A. proved recoverable reserves, B. additional identified reserves, C. additional recoverable resources, D. additional resources and, E. remaining occurrences are included (Figure 4.1 and 4.2). The categories D and E represent inferred and undiscovered occurrences. It is generally assumed that production costs rise and probability of occurrence falls as one goes from the first to the last category. A more detailed representation of China's estimated coal resources (Figure 4.3) indicates that by far the larger part falls in the categories D and E. The categories A-C contain some 15 ZJ hard coal and 1.7 ZJ brown coal.

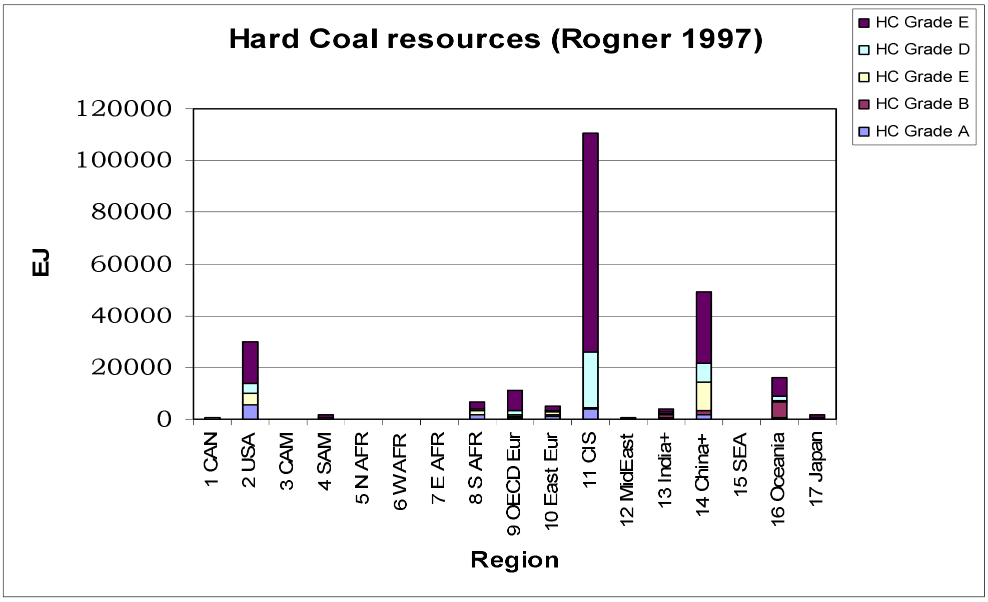


Figure 4.1 Global hard coal resources by region

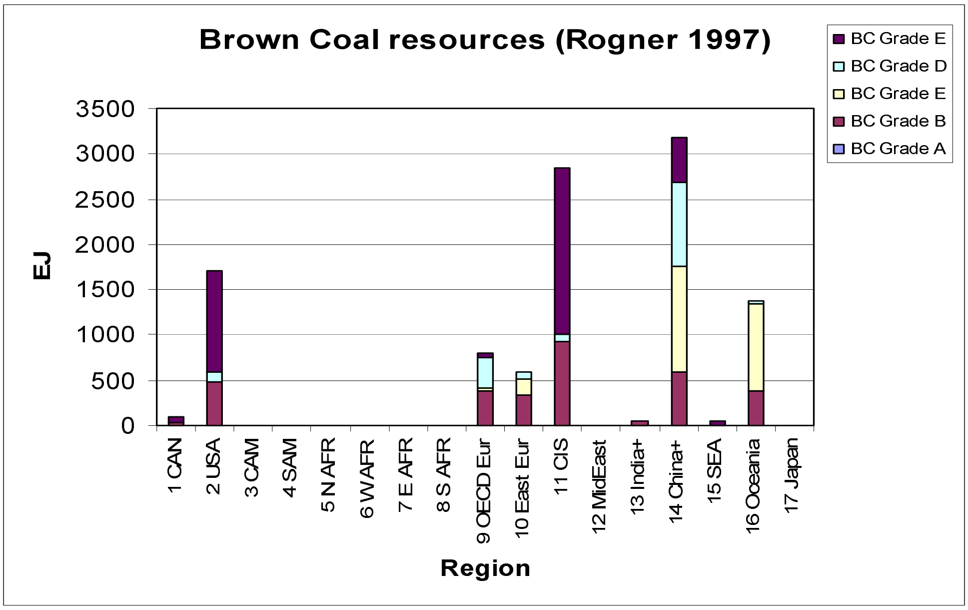


Figure 4.2 Global brown coal resources by region

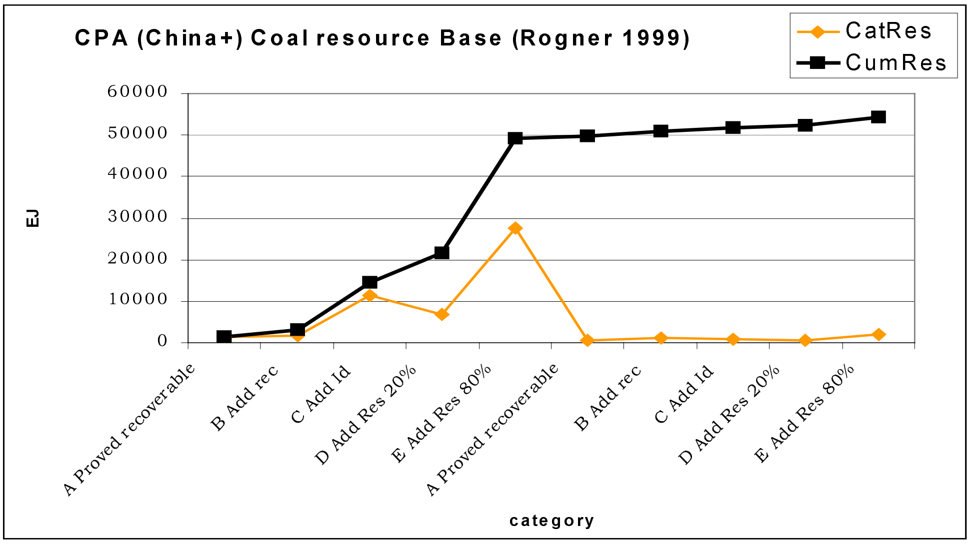


Figure 4.3 Coal resource base of China and other central planning areas

4.1.2 Oil and gas resources

China also has considerable oil and gas in geological resources. According to the assessment on China's oil resources, the total oil resource is about 3900 EJ (93 billion tons). The 'World Energy Resources Survey' prepared for the 15th World Energy Conference in September 1992, showed the assessment of reserves by the end of 1990. Proved recoverable reserves of oil in China were estimated at 138 EJ (3.3 billion tons), accounting for 2.4% of the world total, and the speculative additional reserves at 628 EJ (15 billion tons). For 1997, British Petroleum indicates that Chinese reserves have slightly increased to 147 EJ.

In TIMER currently, Rogner's estimates are used. He divided the resources of oil and natural gas into 8 different categories, covering not only conventional oil and natural gas resources – but also non-conventional resources as indicated under Figure 4.4 and Figure 4.6. The figure, again, shows that China is relatively well endowed with oil, although much less with gas. Not surprisingly, the estimates of proved and speculative additional oil reserves given above are roughly similar to Rogner's categories A and B+C+D respectively. Also the total resource estimate for oil from Chinese sources (3900 EJ) is roughly equal to the category of Rogner covering conventional oil. The unconventional oil resources for the region, estimated by Rogner, are to be more than 6000 EJ, although these are highly speculative and will have production costs. It should be noted that from Rogner's data it could be concluded that even for conventional oil most of the deposits are in the less probable and more costly categories.

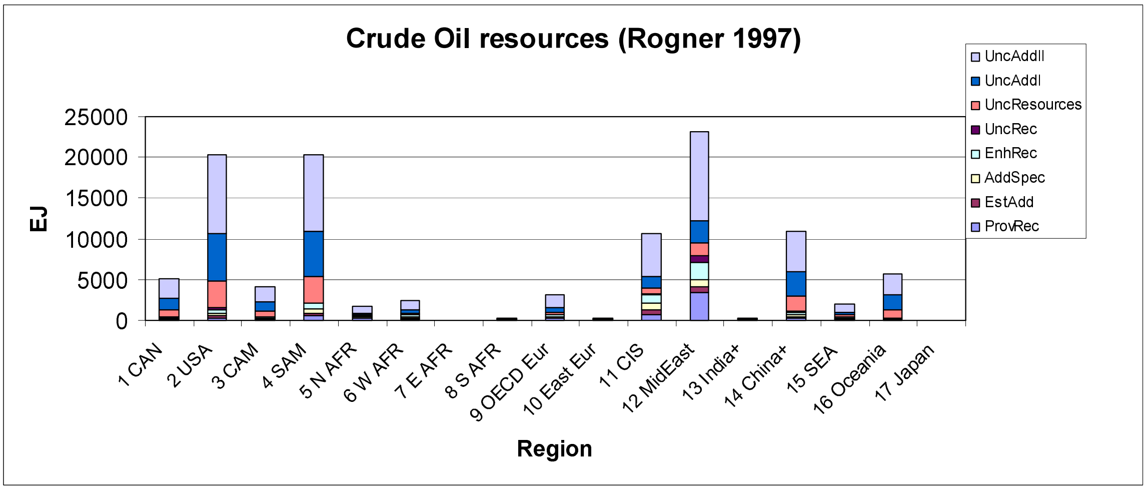


Figure 4.4: Global crude oil resources by region

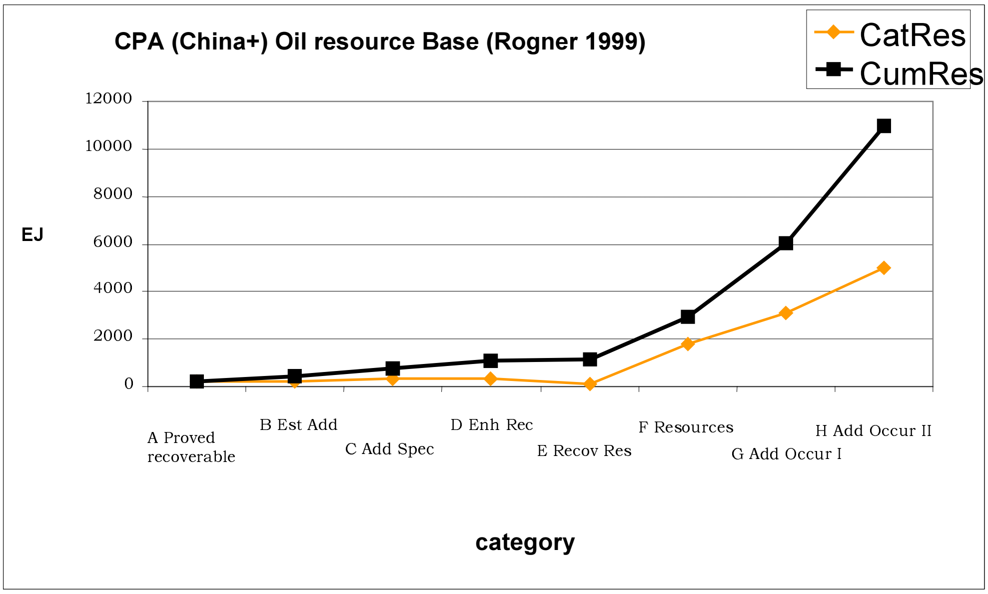


Figure 4.5: Crude oil resources in Centrally Planned Asia according to categories (source: Rogner 1997)

The total gas resource of China has been estimated at 1480 EJ (38×10^{12} m^3). The proven recoverable reserves of gas in 1990 were estimated to be 44 EJ (1.13×10^{12} m^3) and the speculative additional reserves at 77 EJ (2×10^{12} m^3). By the end of 1996, proved gas reserves in China were 94 EJ (2.4×10^{12} m^3), of which dissolved gas 35 EJ (898 billion m^3) and gas bed gas 58 EJ (1.5×10^{12} m^3).

The official estimates of proved recoverable gas reserves (40 EJ in 1990; 94 EJ in 1996) are comparable to Rogner's estimates for category A. However, the estimate of additional speculative gas reserves – 70 EJ – is considerably lower than those of Rogner. The total gas resource estimate of 1480 EJ covers only categories A-E of Rogner's database, apparently omitting the huge unconventional resource that makes up categories F-H in Rogner's estimate.

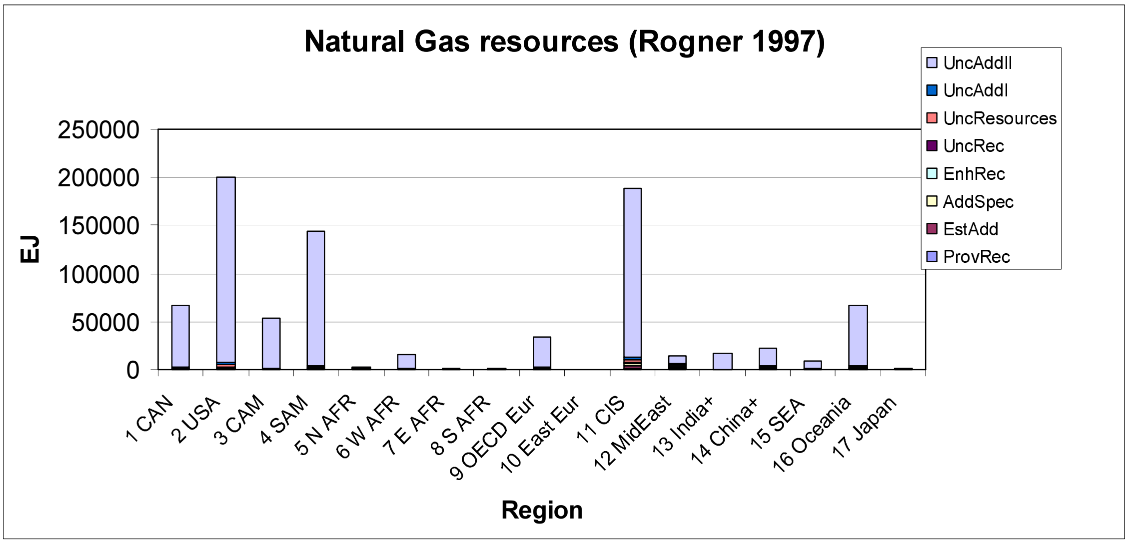


Figure 4.6: Global natural gas resources by region

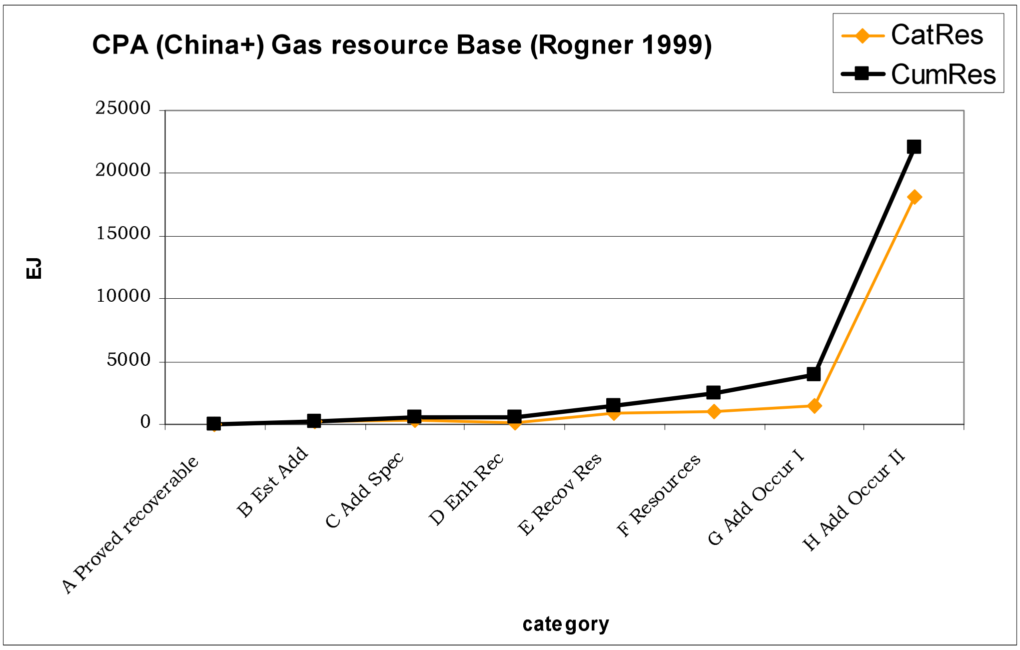


Figure 4.7: Natural gas resources for Centrally Planned Asia by category.

It should be concluded that the national estimates for oil and natural gas resources for China are relatively well in line with the estimates of Rogner (1997) – although the latter also include non-conventional resources (that are highly speculative and relatively costly to produce). China has vast amounts of oil resources, and to slightly lesser extent gas resources. However, for both a large share of these resources are categories that are more costly to produce. Another problem is that China's oil and gas reserve distribution is quite uneven, and approved extent is significant different in different areas. Oil resources mainly concentrate on Northeast China, Northwest China and Bohai Bay. Land natural gas resources mainly concentrate on Sichuan Basin and Shan-Gan-Ning Basin of Central China and Tarimu Basin of West China, offshore natural gas mainly concentrates on South China Sea and East China Sea. A large share of China's oil resources is found in areas with complex geographical conditions for oil production.

4.1.3 Hydropower resource

Hydropower resources in China from rivers was estimated as 676 GW in theory, with an annual generation of 5922 TWh, of which 378 GW and 1920 TWh are evaluated as technically exploitable resources, accounting for 16.7% of the world total (REF). Among the exploitable resources, small hydropower resource (total installed capacity is equal or less than 25 MW) is 76 GW. The recently published World Energy Assessment also contains potentials for hydropower per region. For Centrally Planned Asia, the WEA indicates a technical potential of 2160 TWh (600 GJe)– but also an economically exploitable potential of 1300 TWh (362 GJe). The technical potential is slightly higher than the one cited above.

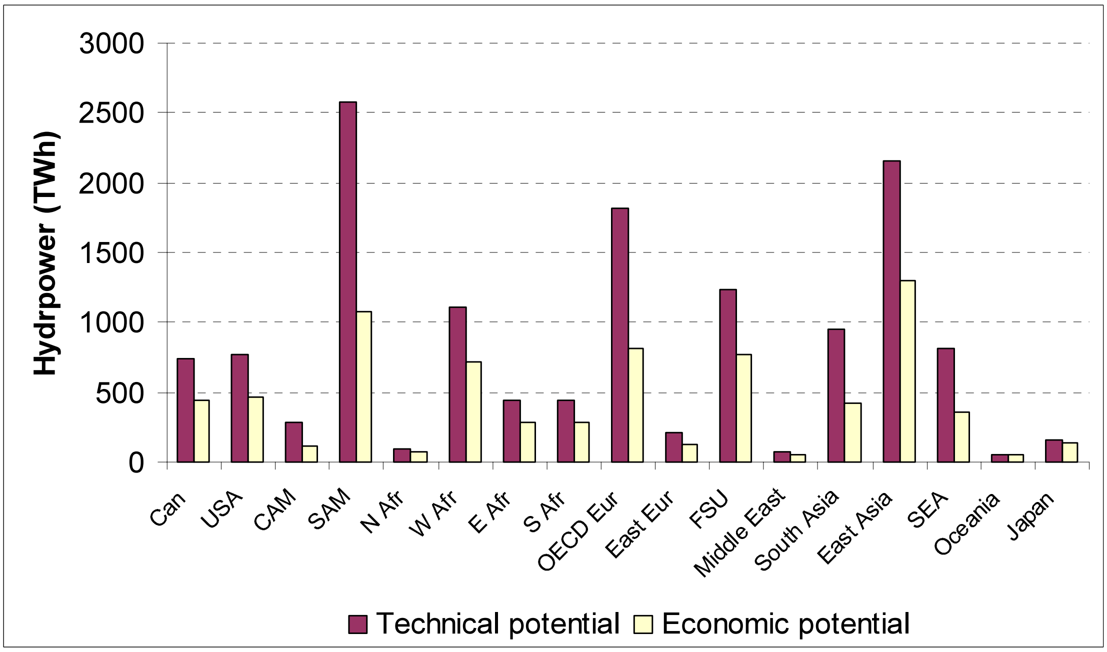


Figure 4.8 Hydropower capacity

Though China has abundant hydropower, the distribution is very uneven. Most reserves are distant from East China where great quantities of energy are demanded. Among the total exploitable hydro power, 67.9% is distributed in Southwest China, the second, 15.4% is distributed in Central China, 9.9% in Northwest China, while only 3.6%, 2.0% and 1.2% is distributed in East China, Northeast China and North China, respectively. Moreover, the geological structure is complex, and exploitation is difficult. Therefore, the exploitation extent of China's hydropower resources is low. In 1990, hydropower resource exploitation and utilisation rate is only about 6.6%. Several other countries in the world show much higher exploitation rates among which the United States (61%), Canada (50%), France (97%), Brazil (18%) and India (13%).

In addition to rivers' hydropower, tidal power is also one of the hydropower resources. China's coastline is as long as 18000 km. According to the general survey conducted in 1982, the installed capacity of exploitable tidal resources is 20.98GW, and annual electricity output is 58 TWh.

The technical hydropower potential in China in TIMER simulations for China is set at 380 GWe, almost the same as the official estimate. Using an average load factor of about 0.42, this could generate about 1400 TWhe/yr.

4.1.4 Biomass resource

Biomass can be used for energy production in several ways. Currently, in China three important methods are used to produce energy from biomass.

The first is the agricultural straw used as fuel. Counted by the agricultural product output, the straw is 550 Mt in 1992, of which 49.3%, namely 136 Mtce (= 4.0EJ), is used as fuel. The second method is the (sustainable) use of firewood. Counted by forestry area and forestry categories, annual sustainable firewood is estimated to be equivalent to 80 Mtce (= 2.3EJ). However, the actual firewood consumption in 1992 is 193 Mt, equivalent to 110 Mtce (= 3.2EJ), the over used firewood is 53 Mt. Over consumption of firewood is one of the important reasons that lead to forestry destruction and water and soil loss. The third part is animal and human manure and organic wastewater. Counted by the animal population, annual manure (dry mass) is close to 300 Mt, being equal to 130 Mtce (3.9EJ). At present, directly burned dry mass in farming and pastoral area is about 7~8 Mt, a small share is used for biogas generation, and the annual biogas output is 1.2 billion cubic meters (=0.025EJ). The share used as energy only accounts for 3% of the total, and the rest 97% is used for fertilizer used in farming land or waste discharged into rivers.

In addition, also special crops could be grown especially to convert them into biofuels. The potential that can be attributed to this option not only depends on total land within a region, its quality to grow crops and the efficiency of conversion but much more demand for land for other reasons, such as food production, forestry, living and nature conservation. This means that estimates are highly speculative. The World Energy Assessment recently published estimates for potential use of biomass per region. In TIMER, potential are used that have been calculated using the land use model of IMAGE 2 (see Hoogwijk et al., 2001). In these calculations it has been assumed that a small share of currently forested areas could be available in the future for biomass production and that in developed regions some part of the current agricultural land could be available for biofuel production. Figure 4.9 shows both the estimates used in TIMER and those of the WEA. Although at the global scale, the high estimate from the WEA and the TIMER estimate are almost equal at the regional level there are very large differences. Most of them can be explained in terms of the assumptions made (e.g. the higher estimates for OECD countries). Also for China, there are large differences between the two sources. The TIMER estimate indicates that 45 EJ could be produced from biofuels. The WEA estimates that this potential is only 11 EJ.

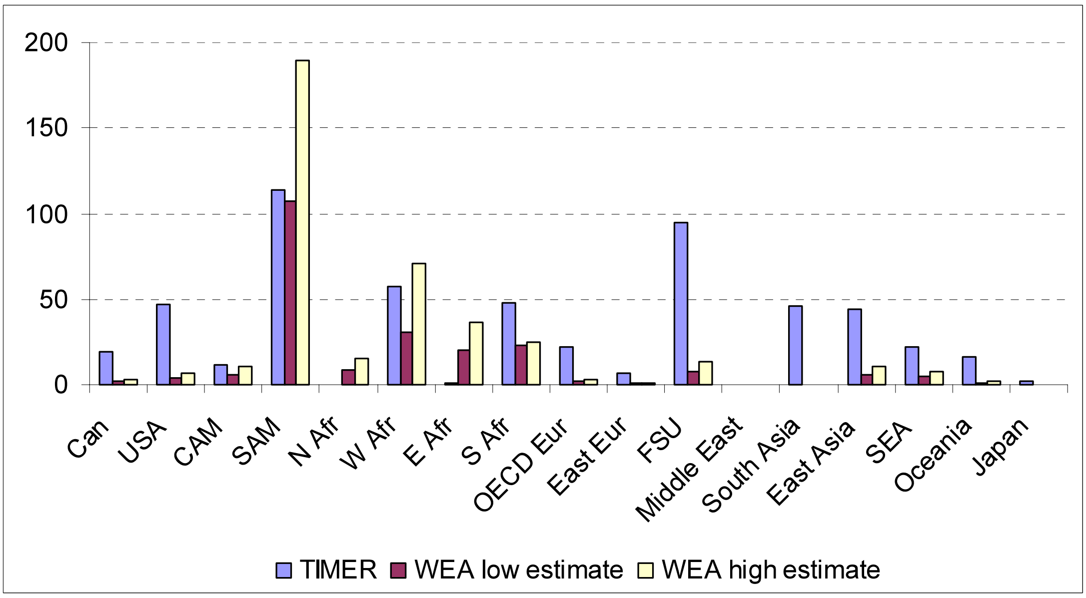


Figure 4.9 Biomass resources

4.1.5 Wind energy resource

Exploitable wind energy resource is estimated as 250 GW in China, which is mainly distributed in two big wind zones. One is coastal wind zone, its effective wind density is over 200 W/m^2, the effective wind emerge frequency is about 80~90%. The other is North wind zone (the line from Xinjiang, Gansu to Inner Mongolia), its effective wind density is about 200~300 W/m^2, the effective wind emerge frequency is about 70%.

The area that is suitable for installing large scale wind generators (with the capacity of 100kW or more) only accounts for around 1% of the nationwide land area. And the area that is suitable for installing smaller generators (with the capacity of 10kW or more) accounts for 10%, and the area that is suitable for installing small scale generator (with the capacity of 1kW or more) only accounts for over 40%.

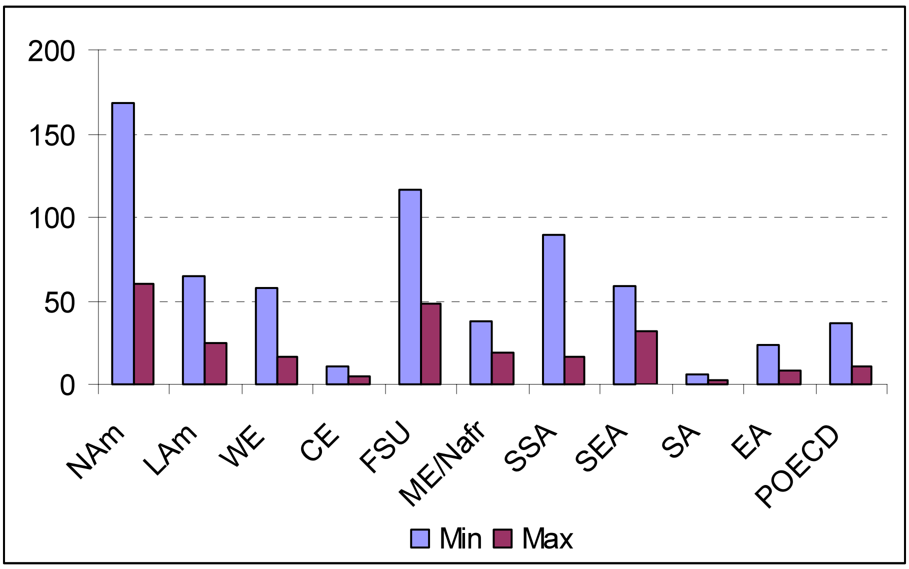


Figure 4.10 Wind energy resources

The World Energy Assessment indicated potential for wind power for different regions in the world. For East Asia, which is dominated by China, the total usable potential was estimated between 10-30 EJ.

4.1.6 Solar energy resource

In theory, China has an abundant solar energy resource. The annual sunshine time is more than 2000 hours in over 2/3 of the land. The average solar radiation is 590 kJ/(cm^2·year) and varies between 335~837kJ/(cm^2·year). Total annual solar energy received by the total land surface is a stunning amount of 50000 EJ. In view of distribution, West and North China, such as Tibet, Qinghai, Xinjiang, Ningxia and Gansu has large solar energy, and the solar energy in Sichuan and Guizhou is least.

However, while the theoretical power for solar energy is very large. The actual technical and economic potentials are much smaller. The World Energy Assessment currently estimates that in East Asia about 120 EJ of solar power could actually be used.

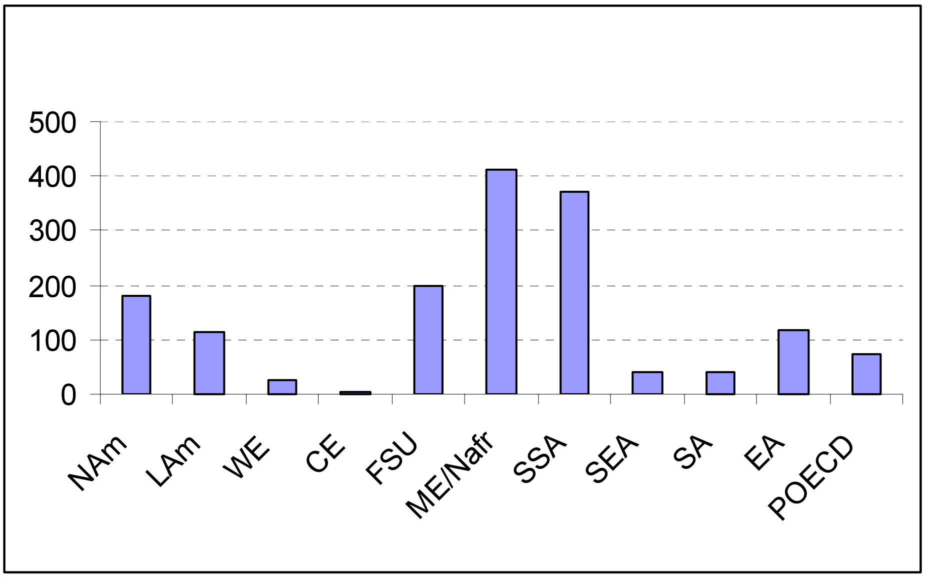


Figure 4.11 Solar energy resources

4.1.7 Geothermal energy resource

According to uncompleted statistic, up to now, there are over 3000 geothermal fields found in China, including hot spring, hot water well and mineral pit hot water (REF). Among which, the number of high temperature water heating system is small, about 175, mainly distributed in Tibet, Yunnan and Taiwan Province. The annual natural heating emission of all geothermal wells and springs is estimated at 104 EJ (3560 Mtce).

According to the investigation on 30 provinces (cities and autonomous regions) conducted by geological departments, proved geothermal resource is about 93EJ (3160 Mtce, speculated geothermal resource is 343EJ (11.7 billion tce), prospective geothermal resource is 13,033 EJ (448 billion tce).

4.1.8 Summary of energy resources in China

In terms of total conventional energy reserves, China is certainly one of the countries that have abundant energy resources in the world. Table 4.1 shows that China's conventional energy resources account for more than 10 percent of the world total.

Though China has abundant energy resources, there are some disadvantages should be paid much attention to. More than 96% of the energy reserves are coal. As the use of coal has worse environmental impacts than oil or natural gas, this is rather unfortunate. Another important disadvantage is energy resource distribution: coal and oil resources are concentrated in North China, and hydropower is in Southwest China, there are little energy resources in the coastal areas that have largest economic activities.

Table 4.1 Conventional energy resource comparison between China and world total

TYPE	PROVED RESERVES (IN 1990)		CONVERT INTO COAL EQUIVALENT (100 MT)		PRODUCTION IN 1992		RPR	
	China	World	China	World	China	World	China	World
Coal	114.5 billion ton	10392	802	7274	1.12	4.5	102	232
Oil	3.26 billion ton	1374	47	1963	0.142	3.17	23	43
Natural gas	1.127×10^{12} m^3	129	15	1700	18.5 billion m^3	2.2* 10^{12} m^3	71	65
Total			1551	14531	1.07 billion tce	10.75	145	135
Uranium [b]		2.356Mt						64
Hydro power	1920 TWh/y	9800	672	3430	131.47	2270 [a]		

Note: 1 coal equivalent: coal: 0.714tce/t; oil: 1.43tce/t; natural gas: 1.33tce/km^3; hydropower: 350gce/kWh, power generation period is assumed as 100 years (1Mtce=29.3GJ)
2 source: World Energy Resource Investigation in 1992, World Energy Commission
[a] power generation in 1991
[b] only for market economy countries in 1988

4.2 Energy production and consumption

4.2.1 Trends in primary energy production and consumption

In terms of both energy consumption and production, China ranks among the largest countries of the world. Between 1980 and 1995, along with increasing economic activities, energy consumption increased rapidly from around 25 EJ (850 Mtce) to 45 EJ (1530 Mtce) (these figures include traditional energy use). Commercial energy use increased even faster, from 17.7 EJ in 1980 to 38.4 EJ in 1995 (see Figure 4.12). Although production and consumption are still almost equal, in this period China turned from a net exporter of energy into a net importer of energy. The share in world-wide energy consumption increased from less than 8.0% to 10.4%. Figure 4.12 shows the China's primary energy consumption in China between 1970 and 1998.

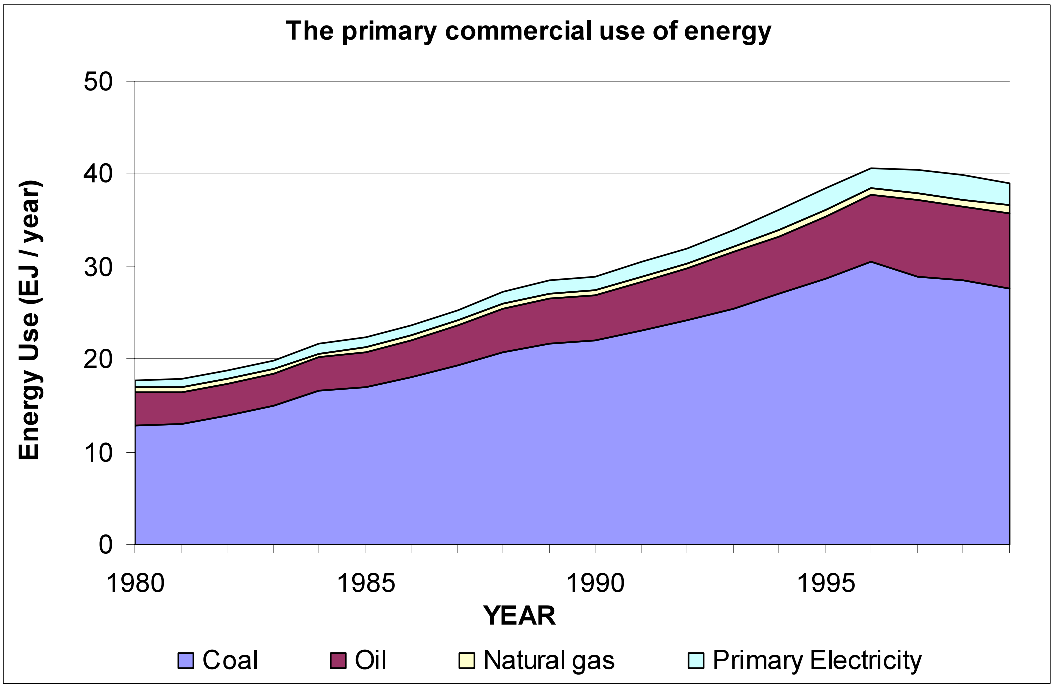


Figure 4.12: Primary energy consumption in China (EJ)

Per capita energy consumption increased at a slightly slower rate, from 18 GJ/cap (0.61 tce/cap) to 33 GJ/cap (1.13 tce/cap), the average growth rate is 3.9%. Thus, during the 16 years, per capita energy almost doubled. However, compared to other countries in the world per capita energy consumption in China is still very low: it is about one half of the world average, and is less than 1/8th of a North American. At present, there are still 40 million rural people who can not access electricity in China.

Primary energy production and consumption structure in China is dominated by coal. During 1980~1996, almost 70-75% of the energy consumption mix was made up by coal, about 15-20% by crude oil ranges, 2-3% by natural gas and 4-6% by hydropower. During the 16 years, generally, the share of oil and natural gas assumed a decreased trend, and the share of hydropower increased, but the speed is very slow.

4.2.2 Coal production and consumption

China is the largest coal producing and consuming country of the world. Between 1980 and 1996, total raw coal output increased from 620 Mt to 1397 Mt, the average annual growth rate is 5.2%. China's coal consumption accounts for 29.5% of the world total in 1996. Appendix A gives sectoral coal consumption for the period 1953-1995. Coal plays an important role in the development in China. It is not only the main fuel of industrial sectors, but also important residential energy and chemical feedstock. In China, coal is mainly used as electricity generation, heating supply, cooking, residential living, chemical industry, building material etc.

4.2.3 Oil and natural gas production and consumption

Between 1980 and 1996, total crude oil output increased from 106 Mt to 157 Mt (average annual growth rate is 2.5%). Of the total oil output in 1996, 142 Mt is produced in land, and the rest 15 Mt is produced in offshore. Appendix A shows the major oil product output. In 1996, crude oil output in China accounts for 4.7% of the world total.

In 1996, total natural gas output in China is 20.1 billion m^3, of which, 17.5 billion m^3 is from land, and 2.6 billion m^3 is from offshore. Total natural gas consumption is 17.11 billion m^3, of which 7.65 billion m^3 (45%) is used for producing chemical fertilizer and other chemical products, 6.72 billion m^3 (40%), is used as industrial fuel and 2.7 billion m^3 (15%) is used for urban residential uses.

4.2.4 Electricity production and consumption

From 1980 to 1996, total installed capacity increased from 66 GW (of which hydropower is 20 GW, accounting for 31%) to 236 GW (of which hydropower is 56 GW, accounting for 24%). In the same period, electricity output increased from 300 TWh (of which hydropower is 58 TWh, accounting for 19%) to 1079 TWh (of which hydropower is 187 TWh, accounting for 18%), as shown in table 2.5. During this period, both the average growth rate of installed capacity and electricity consumption reached as high as 8.3% per year. Electricity consumption structure is shown in table 2.6. The major consumers are industry, residential living, agriculture, commerce, transportation and communication, and construction, in 1996, their shares were 74%, 11%, 4%, 2%, 2% and 1%, respectively.

The electricity industry made a considerable achievement in energy conservation. During the 1985-1996 period, specific coal consumption for electricity supply and for electricity generation decreased from 431 gce/KWh and 398 gce/KWh to 410 gce/KWh and 371 gce/KWh.

China’s nuclear power industry is at the beginning stage, at present, there are 3 units that are operating. The total installed capacity is 2100 MW. One of the three units is in Qinshan Nuclear Power Station (first stage), which capacity is 300 MW, and the other two are in Dayawan Nuclear Power Station, which capacity is 900 MW each. In 1996, nuclear electricity output is 14.2 TWh. There are 8 units with total capacity of 6600 MW which are ongoing constructing.

4.2.5 Rural energy production and consumption

According to the Chinese statistics, the total rural energy consumption in 1996 was 640 Mtce, of which 220 Mtce non-commercial energy and 420 Mtce commercial energy. This accounts for 30% of the nation-wide energy consumption (see table 4.2).
Between 1980 and 1996, there has been significant changes in rural energy consumption structure, in particular an increasing share of commercial energy and a decreasing share of traditional energy. In this period, the average rural energy consumption growth rate is 4.2%, while rural commercial energy consumption growth rate is as high as 9.3%. The ratio of commercial energy to non-commercial energy in rural areas increased from 3/7 in 1980 to 7/3 in 1996; and the ratio of energy for production purposes to residential energy consumption increased from 2/8 in 1980 to 5/5 in 1996.

Table 4.2: 1996 Rural energy consumption (Mtce) (1Mtce=29.3GJ)

Type	Residential	Agricultural production (including TVEs) *	Total
Commercial			
Coal	100	178	278
Oil products	2	45	47
Electricity	29	68	97
Subtotal	131	291	422
Non-commercial			
Firewood	83	16	99
Straw	120	-	120
Subtotal	203	16	219
Total	337	284	641

* TVEs: Town and village enterprises
Source: 1997 Energy Report of China

4.2.6 Renewable and new energy sources

With regard to renewable and new energy sources, the following observations can be made:

- *Small hydropower:* According to 'the 98 Global Small Hydropower Conference' held in Hangzhou, China in March 1998, the number of small scale hydro PowerStation's in rural areas of China reached 46000, and the total installed capacity is 21.8 GW. The annual electricity output is 73 TWh, accounting for 40% of the world total. Small hydropower plays an important role in electrification of rural areas in China.
- *Biogas.* By the end of 1996, China has established more than 600 large and middle scale biogas pits. The annual biogas output reached 1.586 billion m^3 and 86,000 households are centrally supplied with biogas. In addition, there are 154 biogas power stations, and the total installed capacity is about 3 MW.
- *Wind energy.* By the end of 1996, there are 14 in-grid wind power stations established in China. The total installed capacity is 56.5 MW. At the same time, there are 140,000 small units that are operating in remote areas and islands, these units' scale is no more than 5 kW each, which total installed capacity exceeds 17 MW.
- *Solar energy.* By the end of 1996, the installed PV cells capacity reached 7 MW. The largest PV station lies in Ali of Tibet of which the capacity is 25 kW. Water heater consumption reached 5 million m^2 in 1996 which means that China's water heater utilisation and production capacity ranks first in the world.
- *Geothermal energy.* By the end of 1996, total geothermal installed capacity reached 28.6 MW, of which, the capacity of Yangbajin Station, Tibet is 25 MW. This unit provides 41% of Lhasa grid, and its accumulated electricity output has exceeded 500 GWh. The direct utilisation of middle and low temperature hot water, such as space heating, greenhouse etc, mainly concentrates in Tianjin, Beijing, Hebei and Fuzhou, annual utilisation is equal to 400 ktce.
- *Tidal energy.* At present, China has established 7 tidal power stations, which total installed capacity is 6 MW, of which, the capacity of Jiangxia Tidal Power Station, Zhejiang is 3.2 MW. In addition, a tidal current power station is established in China, which capacity is 5 MW. There are more than 300 small wave power stations that are used for electricity supply of navigation lamp.

To have a detail view on the end energy consumption, end energy consumption by sector and by energy carrier of China in 1995 is shown in table 4.3.

Table 4.3 China end energy consumption and structure by sector in 1995 (1Mtce=29.3GJ)

		Residential		Agriculture		Industry		transportation		construction		service		Total	
		Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%	Mtce	%
Energy carrier	Coal	94.9	60.3	13.24	24.0	327.43	36.6	9.35	16.5	3.15	23.6	20.86	31.9	468.94	37.7
	Coke	1.28	0.8	1.25	2.3	100.39	11.2	0.10	0.2	0.10	0.7	0.31	0.5	103.43	8.3
	Fuel oil	0	0	0.12	0.2	28.05	3.1	3.23	5.7	0.20	1.5	0.53	0.8	32.13	2.6
	Gasoline	0.94	0.6	2.64	4.8	11.95	1.3	14.45	25.5	1.52	11.4	11.3	17.3	42.81	3.4
	Diesel oil	0.23	0.1	14.52	26.4	15.32	1.7	18.08	31.9	1.71	12.8	10.86	16.6	59.01	4.7
	LPG	9.13	5.8	0	0	3.26	0.4	0.01	0	0.01	0.1	0.39	0.6	12.80	1.0
	Natural gas	2.58	1.6	0	0	19.03	2.1	0.09	0.2	0.04	0.3	0.23	0.4	21.98	1.8
	Electricity	38.07	24.2	22.05	40.0	261.77	29.3	6.90	12.2	6.04	45.2	16.42	25.1	351.24	28.3
	Others	10.39	6.6	1.27	2.3	127.05	14.2	4.36	7.7	0.57	4.3	4.51	6.9	149.10	12.0
	Biomass	(251)													
total(vertical)		157.4	100	55.05	100	894.73	100	56.58	100	13.34	100	65.37	100	1242.53	100
total(horizontal)		157.4	12.7	55.05	4.4	894.73	72.0	56.58	4.5	13.34	1.1	65.37	5.3	1242.53	100

Note: biomass consumption is not counted in total
Source: National Statistical Bureau, The Ministry of Agriculture

4.3 Energy efficiency

During 1980~1996, primary energy consumption in China increased from 603 Mtce to 1388 Mtce, average annual growth rate is 5.2%; Electricity output increased from 301TWh to 1079 TWh, average annual growth rate is 8.2%. In the same period, the average annual economy growth rate was 9.9%. Therefore, it can be calculated that the energy consumption elasticity and electricity consumption elasticity have been 0.53 and 0.83, respectively. This means that China has made great achievements in energy conservation.

In other way of putting this is that average energy use per 10000 yuan RMB GDP (counted by 1990 constant price) decreased from 7.64 tce in 1980 to 3.91 tce in 1996. There are two reasons for this. First of all, there have been some changes in the structure of the economy – although these have been relatively small. Secondly, unit energy consumption of major industrial products decreased significantly. At the same time, it is clear that the energy intensity in China is much higher than many of the industrialised countries, indicating that there is still a large potential for energy conservation in China.

4.4 Comparison of TIMER data and Chinese statistics

In the original version of the TIMER model, China is part of the region East Asia[5] which is one out of the 17 regions of the model. The calibration of the model has been done based on international data, mainly from Worldbank, UN and the International Energy Agency. Obviously, in China mostly statistics from domestic resources are used. In the project, we have explored the question about what are the differences and the reliability of the various historical data and how does regional aggregation, affect the results? Table 4.4 gives an overview of the various available data sources for our project.

Table 4.4: Sources of information for the different sub-regions within East Asia [6]

Available data:	Population	Economy	energy
Region:			
China P.R.	UN/WB, ERI	WB, ERI	WB, IEA, ERI
Hongkong	UN/WB	WB	WB, IEA
S. Korea	UN/WB	WB	WB, IEA
N.Korea	UN/WB		IEA
Taiwan	UN		IEA
Macau	UN/WB	WB(82-98)	
Mongolia	UN/WB	WB(81-98)	
TIMER-14	UN/(WB)		IEA (adjusted)

[5] East Asia is region 14 in the TIMER model.

[6] Abbreviations: UN: World Population Prospects 1996, UNDESD / Population Division. WB: Based on World Development Indicators 2000 (WDI2000), World Bank IEA: IEA database 1998, Energy Statistics. ERI: Digitally received (22-11-2000) from The Center for Energy, Environment and Climate Change Research of Energy Research Institute, State Development Planning Commission, China.

Population

In the original East Asia region, the population of the China Peoples Republic (China P.R.) is by far the largest (see Figure 4.13). The historic data for China itself is almost similar for the Chinese statistics and the UN data used originally by TIMER. In Figure 4.13 we have also included the projection made by experts (C1/C2) and the projections for the East Asia region included in the SRES scenarios (A1, B2, A2 and B2). The Chinese projection for P.R. China shows an annual growth rate of slightly more than 0.5 percent for the period 1995 to 2050. In the SRES scenarios (East Asia) the growth varies from 0.1 (A1, B1) to 1.0 (A2) percent for the 1995-2050 period. The SRES-scenario B2 with a growth of 0.4% percent is closest to the Chinese projection.

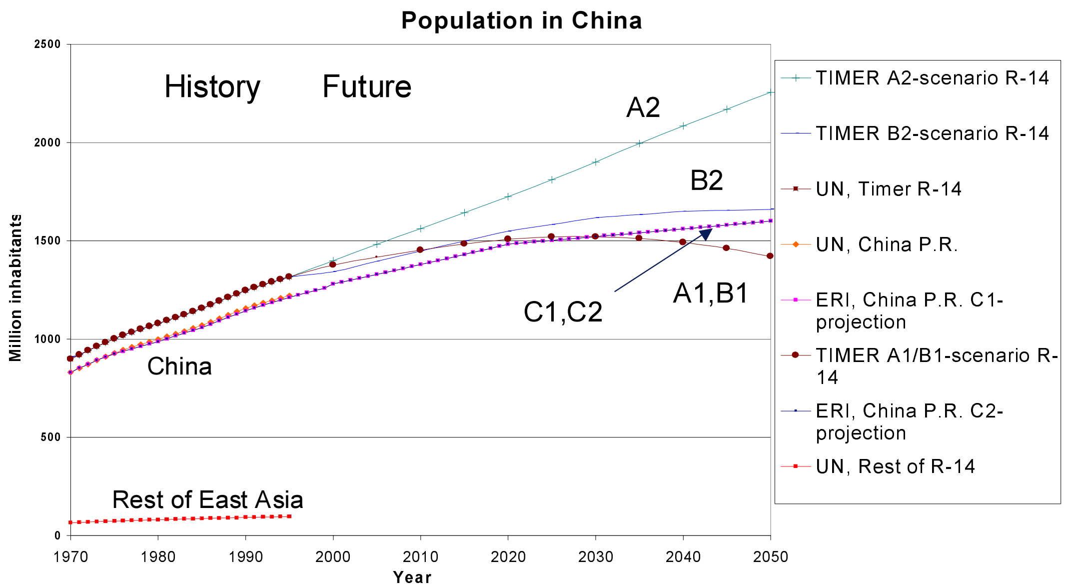


Figure 4.13. The population for East Asia (TIMER Region-14), China and the rest of East Asia based on different sources.

National Income

The data used by ERI for GDP growth in China has been taken from the World Bank data set to ensure consistency with other countries. The growth level is around 8.2% for the period 1970 till 1995. The GDP of the total East Asia region is considerably larger than that of China only (in 1995 it is about twice the value) (see Figure 4.14). This implies that the per capita income for some of the other parts of the East Asia region is at a significant higher level than that of China.

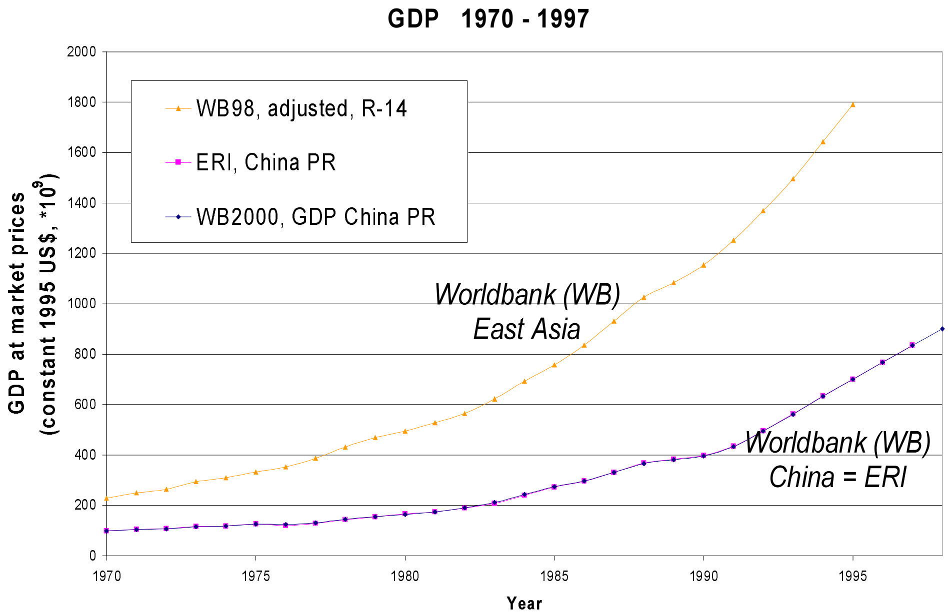


Figure 4.14: Historic GDP for China PR based on WB and ERI

Figure 4.15 compares the historic development of GDP in China and East Asia to two scenarios for the future development of GDP as used in the original version of the TIMER model. In these scenarios total GDP of East Asia reaches the the value of USA in 1995 somewhere between 2020 and 2030.

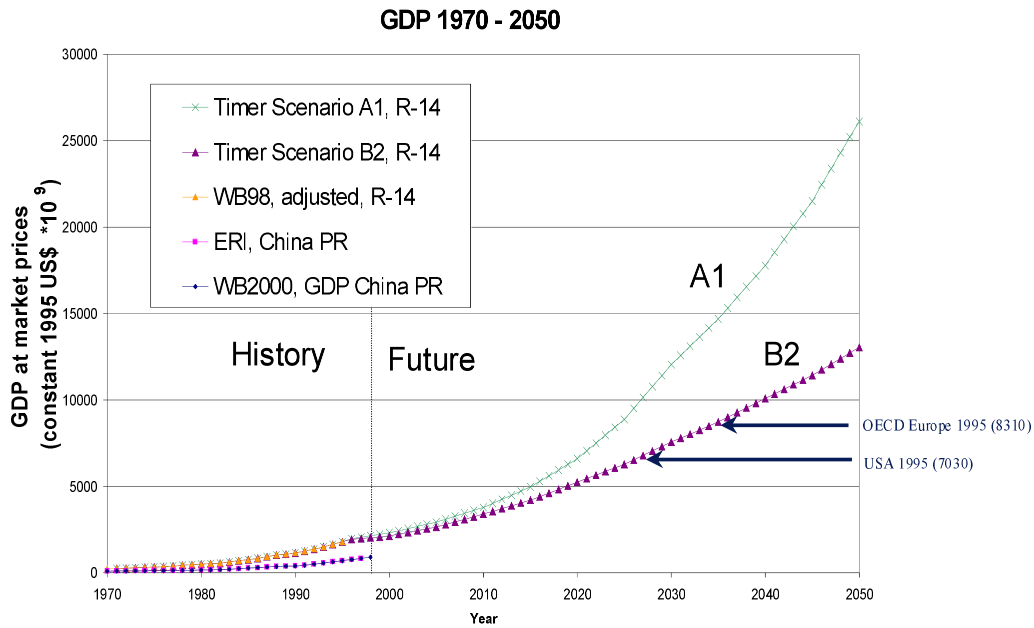


Figure 4.15: TIMER/IMAGE SRES A1 and B2 scenario projections of GDP for East Asia

The Energy Research Institute (ERI) has developed projections for the GDP for China P.R. till 2100, the so-called C1 and C2-projection that are used within this project (see Chapter 5). In the C1 projection a growth of 5.3% between 2050 and 1995 has been applied, while the C2 projection a slightly higher growth of 5.9% for the same period shows. Figure 4.16 compares these scenarios to the scenarios for East Asia of the original TIMER model.

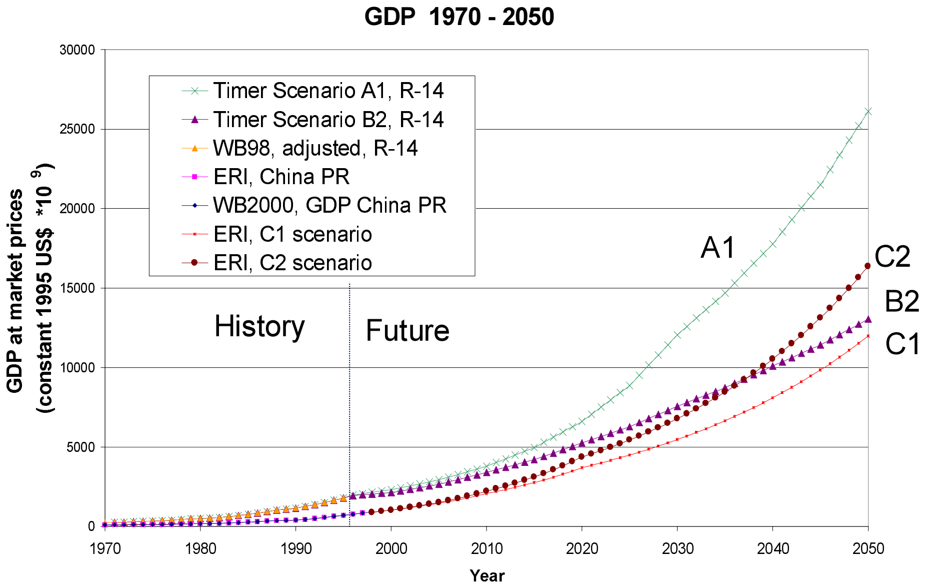


Figure 4.16: The scenarios for GDP in China as used in this project compared to the East Asia projections for the SRES scenarios of TIMER/IMAGE.

Not only the level of GDP has changed, but also the economic structure as discussed earlier in this chapter. Figure 4.17 compares the current structure of the Chinese economy to that of South Korea. This figure shows that South Korea has much more developed towards a service driven economy. It can be expected that economic growth in China will imply that also here the service sector will grow significantly.

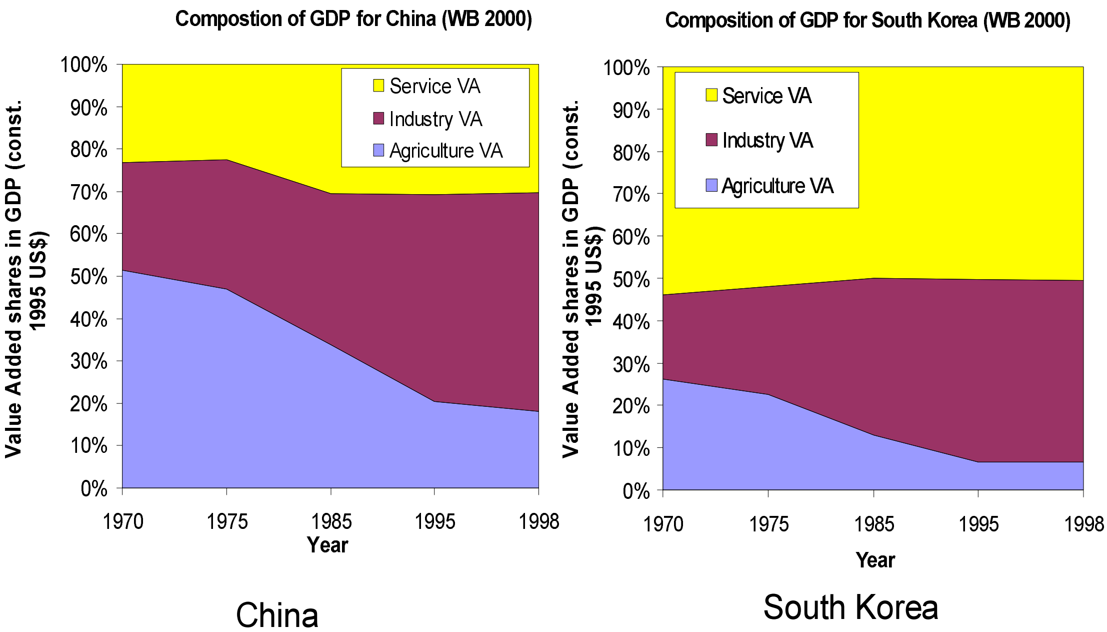


Figure 4.17 Composition of GDP (VA Agriculture, VA industry VA services) for China PR and South Korea based on UN/WB and ERI data

Energy use

Comparing the energy data for China from international sources and national sources is complicated by the different accounting methods. For instance, energy use for freight transport is recorded under transport in international statistics and under industry in Chinese statistics. Also for electricity use, different accounting methods exist. After correction for these differences in accountings, the differences left were minor. It is clear coal has become the major fuel within China after 1978, surpassing the energy use from biomass. Still traditional biomass, maintains a quite significant role in energy supply.

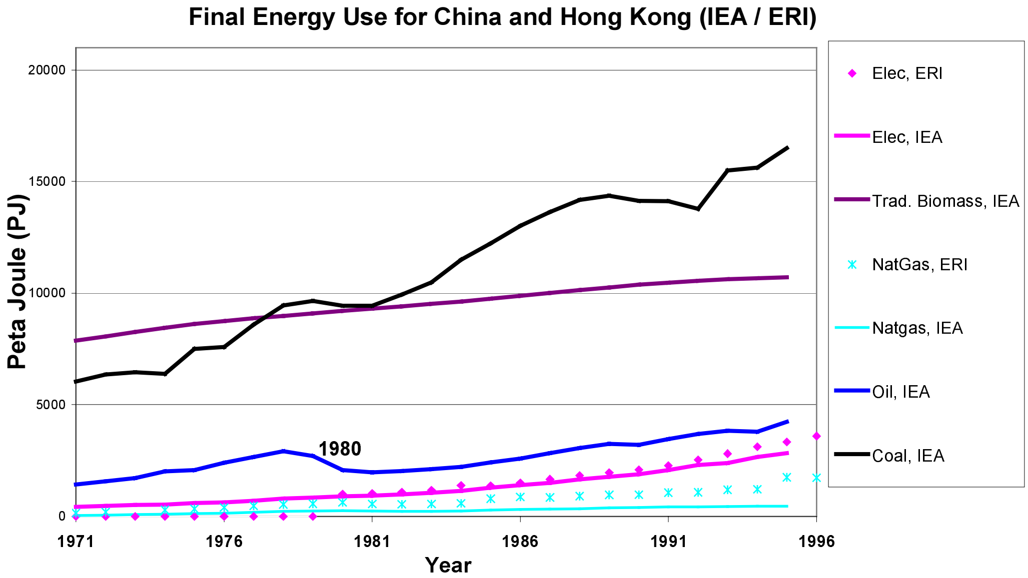


Figure 4.18: Final energy use compared in mainland China and Hong Kong

Energy intensities

Energy intensity indicators for China have been calculated based on UN/WB, IEA data. The industry sector showed a roughly constant intensity (energy use over industrial value-added) in the first part of the eighties. Since 1987, for the industry sector an impressive reduction can been registered, the intensity has halved in the period from 1987 till 1995, according to UN/WB and IEA data. For the service sector (sectoral energy consumption over service value added), no clear trend in energy intensity can be noticed over the whole period from 1980 to 1995. The transport sector and the residual sector 'Other' peaked in 1978, where after it start its continuous decline till 1995. Energy intensity in the transport sector (sectoral energy consumption over GDP) declined by about 50% since 1971 and even more since 1978. The energy intensity sector 'Other' (sectoral energy use over GDP) declined by more than 65%, according to UN/WB and IEA data. The intensity of the residential sector (energy consumption over private consumption) showed the most constant and also the largest decline in energy intensity namely almost 75% in 24 years. Because of data limitations, for the industry sector and service sector only intensity indicators could be calculated since 1980.

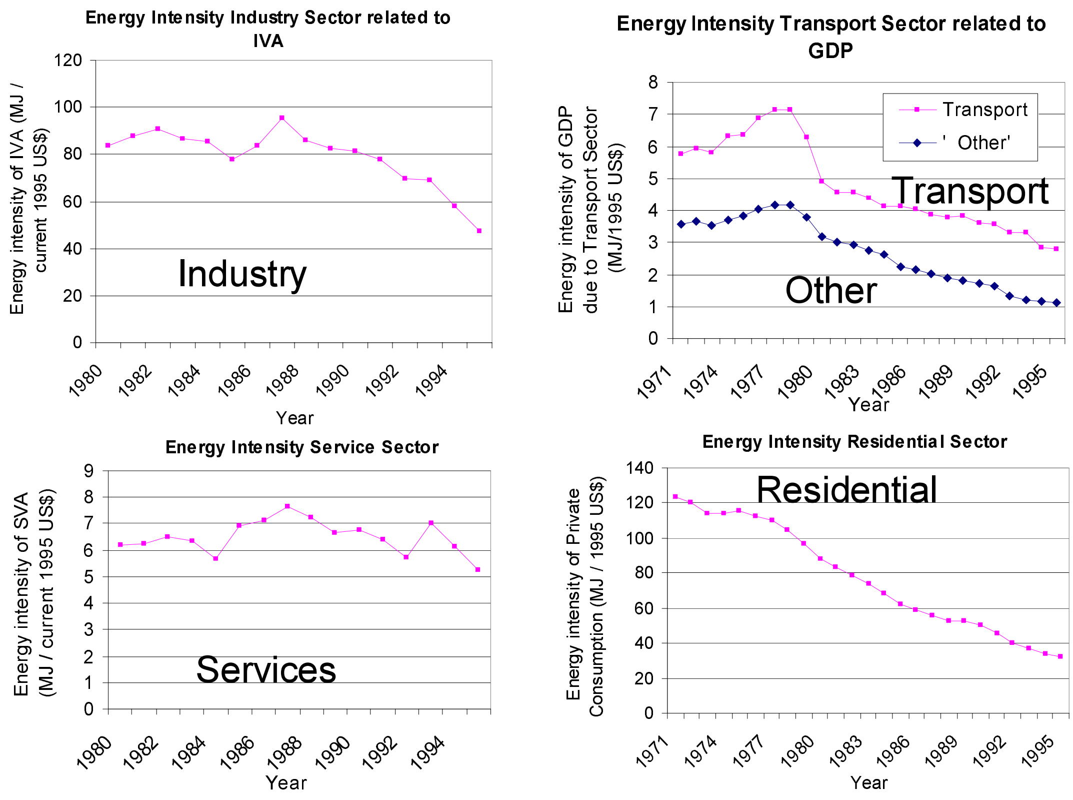


Figure 4.19: Calculated energy intensities for China based on UN/WB and IEA data

As the ERI data for energy use is almost similar to the international data for China, we have not shown the trend in these statistics separately. Overall one might conclude, that the reduction in energy intensity have been impressive in the last two to three decades, and most significant have been the decline within the residential sector, followed by the rest category 'Other' sector and the transport sector.

Conclusions:
Overall, it can be concluded that the international and domestic data sources for China are in relatively good agreement. At the same time, it is also clear that there are large differences between the data for the Region East Asia (original TIMER region) and China. We have therefore decided to recalibrate the TIMER model changing the East Asia region into a region with only China. This new TIMER model has been based on the national statistics for China as supplied by ERI.

4.5 Changes in recent years

In 1996, both energy production and consumption in China peaked. After 1996, energy consumption has started to decline (this has been confirmed by Fridley, 1999; EIA, 2000; Logan, 2000). The decline varies from half a percent in 1997 to two percent in 1999. The decline in fact is explained by the decrease in the use of coal. The latter energy carrier showed a decrease of respectively 1.5% and 4.8%. The use of other energy carriers for the same period however, has not been decreasing but mostly show a small increase. The decline in the use of coal most seriously took place in the direct energy use. Coal use for intermediary use like for electricity production, district heating in towns and gas production has shown a more or less stable level of use. As a consequence, Chinese carbon dioxide emissions have declined as well after 1996, as shown in Figure 4.20.

Table 4.5 Energy production in China in recent years (1Mtce=29.3GJ)

	Total (Mtce)	Coal (%)	Oil (%)	Natural gas (%)	Hydro and nuclear power (%)
1996	1326.16	75.2	17	2.0	5.8
1997	1324.10	74.1	17.3	2.1	6.5
1998	1242.50	71.9	18.5	2.5	7.1
1999	1100.00	68.2	20.9	3.1	7.8

Table 4.6 Energy consumption in China in recent years (1Mtce=29.3GJ)

	Total (Mtce)	Coal (%)	Oil (%)	Natural gas (%)	Hydro and nuclear power (%)
1996	1389.48	74.7	18.0	1.8	5.5
1997	1381.73	71.5	20.4	1.7	6.2
1998	1322.14	69.6	21.5	2.2	6.7
1999	1220.00	67.1	23.4	2.8	6.7

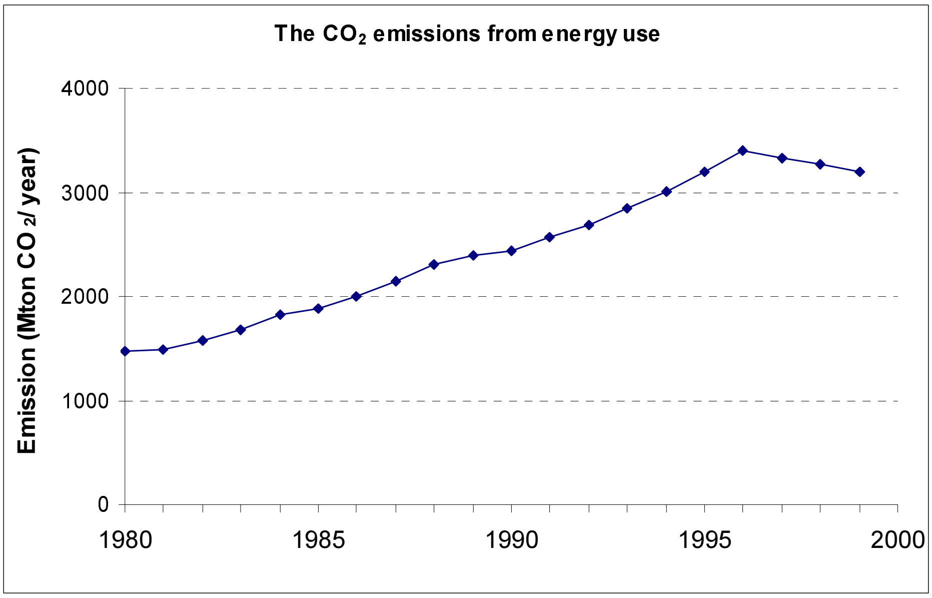


Figure 4.20: Carbon dioxide emissions in China between 1980 and 1999.

The decline in energy consumption is remarkable as the economy in the same period still increased by about 6% per year. There are some explanations that can be given for this phenomenon. It is not clear yet how much reduction should be attributed to each of these explanations:

- Lower economic growth between 1996 and 1999;
- Changes in the quality of coal, due to the development of a so-called ‘buyers’ market;
- Improvement in the efficiency of energy use within China because of closure of a part of the inefficient state firms and in addition policies focused on energy-efficiency improvement;
- Improvement of the efficiency of electricity generation;

- A shift towards other energy sources replacing coal.
- Adjustment of national economic structure, the share of heavy industry, including energy intensive industry decreased, which reduced the demand on coal.
- The import of energy intensive products increased, which reduced the demand on coal.
- Residential use of coal has fallen as more urban dwellers move into apartments with central heating and consumers switch to electricity and gas for cooking and water heating.
- Reductions in energy use are overstated; energy consumption is significantly greater than production as China's enormous stockpiles of coal are used, and recent or historic energy and economic statistics are inaccurate.

We will shortly discuss some of these explanations in more detail.

Economic growth
Sinton and Fridley conclude in their that the slowdown of economic growth in China after 1998 proved to be a relevant factor for the emission reduction (during the 'Asian' crisis). Although the economic growth still stayed at a level of about 5-6% per year, it is lower compared to the previous period. As a result, growth in electricity demand slowed down (with possibilities for rationalising the electricity supply) and some sectors even shrunk in size, like the sector with energy-intensive construction materials and the chemistry sectors. Together, both the energy-intensity improvement and the slow down of economic growth has led to a decrease in absolute energy use.

Structural changes in the economy on the level of macro-sectors, barely has played a role in the change of energy-intensity. As indicator, the share of the industrial sector in the total value added stayed in fact on a fairly constant level. Within sectors however, significant changes appeared, like a changed product mix towards products with high quality and added value per unit energy used.

Quality of the coal
A quite important cause for the reduction in energy demand in these recent years is the improvement in quality of the coal that has been used (quality here indicates the energy content per ton of coal). Sinton and Fridley (2000) conclude that 40% of the decrease in energy demand after the 1996 peak, is a result from the better quality coal. The improved coal quality is a result from the appearance of the so-called 'buyers' market. Due to the oversupply of coal, there was the possibility for users to get their coal for a reasonable low price and even of better quality with higher energy content. Obviously, coal will soon meet its maximum quality level.

Improving efficiency
China has initiated a strong policy in privatisation of its economy. It implies that the closure of state companies, which in many cases appeared to be inefficient users of energy. As a result the efficiency showed an important improvement. Private companies in many cases have newer equipment and a better management. Also the period of slowdown in economic growth has possibly contributed to the closure of production sites with less efficient processes. In the period 1996-1999, for example, a serious number of small low efficient production plants for ammonia have been closed.

Improvement of the efficiency of electricity generation
Within the electricity sector there exist a continuous trend to a higher efficiency. The Chinese government has developed a policy to close all units smaller than 50 megawatt and to replace by bigger more efficient units.

Price-oriented energy market
Since 1990 the energy prices in China has risen strongly, partly due to the liberalised markets and the reduction of subsidies. The strongest price increases however occurred before 1995.

Limitations in statistics
The quality of the available statistics are not undisputed. Some suggest even difference up to hundred million ton of coal (Fridley, 1999). A special problem make the changes in the stockpiles in particular those of coal. Some years ago, the coal stocks had an enormous size, even more than 150 million ton. Several indications proves that in recent years a significant part of these stocks have been used. In the article of (Sinton et al., 2000) it is estimated that for the years 1997, 1998 and 1999 the available stocks of coal mined, has been increased with respectively 13 million tonnes, and 50 respectively 90 million ton has been decreased. After that, there is the phenomenon of unbalance between on the one side total supply and on the other side total use of coal, with for the most recent years a growing exceeding consumption over total supply.

Moving towards other energy sources
A long-term trend what can be observed in the Chinese energy-supply is the (slow) but continuous switch towards other energy forms, different from coal. As said in the introduction, in the period of 1995-1999, the use of oil, gas, hydropower and nuclear energy hasn't been diminished, but has been extended. One explanation comes from the environmental policy in the big cities, where purposely the choice is made to replace coal by Liquefied Petrol Gas, natural gas, town gas and electricity. As far as is known this trend hasn't been quickened.

Conclusion
The drop in carbon emissions in China between 1996 and 1999 is mainly caused by a number of short-term effects that appeared on top of a set of long-term trends. These short term effects were the slowed economic growth, the very strong change in the quality of the coal and the accelerated closure of inefficient industries because of excess capacity. Long-term trends that – to a limited extent – work into the same direction, is the normal energy-efficiency improvement in end use and in electricity supply, the abolition of subsidies and a slow moving fuel mix. These findings all depend on the limitations in quality of statistics on what actually happens within China.

5. Baseline scenarios for China

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 et al., 2000). Using the SRES approach, we have developed in this study several baseline and policy scenarios 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.

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

- First, we have developed 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 (Chapter 5).
- Second, we have developed 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[7] (Chapter 6).
- Third, several mitigation scenarios have been developed. These scenarios aim to identify the potential of different policy options to abate GHG emission in China (Chapter 7).

5.1 The Global IPCC SRES scenarios

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. Box 5.1 gives an overview of the storylines of these scenarios.

[7] 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, in addition to China, North and South Korea, Taiwan, Mongolia, Hong-Kong and Macao.

Box 5.1: Storylines of the SRES scenarios

The *A1 storyline* and scenario family describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into four groups that describe alternative directions of technological change in the energy system.

The *A2 storyline* and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

The *B1 storyline* and scenario family describes a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

The *B2 storyline* and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

5.2 Scenarios for China

We have developed a set of storylines for the Chinese scenarios based on an export workshop in January 2001 in Bejing. The storylines are described below.

A1b-C Scenario: an 'open' China in a globalised world

The first scenario follows the story line for the global A1b-C-scenario[8], 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. The A1b-C scenario can be seen as a 'catching-up' scenario: China's per capita GDP is assumed to be close to the 1990 level of the OECD countries in 2050, at about US$ (1995) 10,500. 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. In this respect, the development path of China follows that of OECD countries in the past. 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 global population grows to some 9 billion by 2050, and declines to 7 billion by 2100.

The economic development in the A1b-C scenario provides support for technology R&D and innovation. As globalisation allows for rapid spread of technologies, renewable energy and

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

other clean energy technologies will become available on a large scale. Within this scenario, several fuels such as coal and traditional biofuels can be expected to lose market shares in end-use sectors for reasons of convenience and avoiding local air pollution.

B2-C Scenario: China geared to solving regional environmental problems
This scenario follows the SRES B2 story line. It assumes a slightly lower economic growth with limited trade and technology transfer among world regions. The basic consideration in this scenario for China is that economic development will utilise 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 recognised as serious problems and make environmental sustainability in the region an important priority next to equity considerations. This scenario can be described as regional stewardship, based on a natural evolution of the present institutional policies and structures.

The growth of the population is assumed to be the same as in the A1b-C scenario. Considering the emphasis of the B2 scenario, namely more focus on environmental protection and more dependency on domestic resources, the economic growth rate is lower than that 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.

5.3 Social and economic indicators of the baseline scenarios

Social and economic development is a determinant factor for energy demand, so it is necessary and important to make some assumptions on future social and economic development for energy demand forecast.

TIMER/IMAGE model is the tool of this study. It is a global model and the global is broken into 17 geographic regions. The original 14^{th} region includes Mongolia, DPRK, South Korea, Taiwan of China, Hong Kong of China and Mainland China. Considering the different situations and the purpose of this study, we just focus on Mainland China (hereinafter China) and it becomes the new 14^{th} region.

For each region, economic system consists of 5 sectors: industry, transportation, residential, service and other. Driving forces include population, the share of rural population, GDP per capita, value-added per capita of industry (for industry sector), value-added per capita of transportation (for transportation sector), private consumption per capita (for residential sector), value-added services per capita (for service sector), and GDP per capita of other (for other sector), etc.

5.3.1 Population and urbanisation rate of China

Though population control is one of the national basic policies, birth rate and growth rate have decreased continuously, there is still pressure on population increase from age structure. There will be a considerable increase in population before 2020, then the growth rate will go down. However, it is widely accepted that the population can stop increase only around 2050.

Many organisations forecasted the future population of China (see tables 5.1 – 5.3).

Table 5.1 Population forecast of China (1) (million)

	2000	2010	2020
Asia-Pacific Integrated Model(AIM)	1284	1393	1472
Quantitative Economic Institute of CASS	1330	1480	1518
Chinese Academy of Sciences(CAS)	1282	1400	1500
Asia Development Bank(ADB)	1294	1386	1498
The World Bank(WB)	1300	1400	1447
United Nations Environmental Program(UNEP)	1294	1390	1450
Energy Research Institute(ERI)	1304	1415	1496

Table 5.2 Population forecast of China (2)

	1995		2000		2010		2020
Population by the end of the year (million)	1216		1280		1379		1483
Birth rate (‰)		17.16		15.27		15.39	
Death rate (‰)		6.48		7.77		8.09	
Natural growth rate (‰)		10.70		7.50		7.30	

Source: China: Stride forward 2020, China Planning Publishing house, 1997

Table 5.3: Population forecast of China (3)

	1995		2000		2010		2020
Population by the end of the year (million)	1221		1285		1388		1488
Birth rate (‰)		17.30		15.20		14.90	
Death rate (‰)		7.10		7.30		7.90	
Natural growth rate (‰)		10.10		7.80		6.90	

Source: UN, World population prospect, the 1994 revision, New York, 1996

Table 5.3 shows the results of medium forecast made by UN, which are close to the results in table 5.2. The general trend is that the natural growth rate will gradually decrease. The target of the Chinese government will be realised, which is stipulated in the Outline for 'Ninth-five year' Planning and Perspectives on Social and National Economy development through 2010, namely, control the population less than 1300 million by the end of 2000 and 1400 million by the end of 2010.

Urbanisation is an important factor for economic and social development. Table 5.4 represents the urbanisation forecast results made by different organisations.

Table 5.4: Forecast on urbanisation rate in China (%)

	2000	2010	2020
AIM	32.1	38.1	43.0
CASS	37.6		48.4
ADB	32.4	38.4	44.4
WB	31.0		42.0
UNEP	31.4	37.4	44.8
ERI	31.5	37.5	45.0

Since the forecasts of population and urbanisation made by different organisations are not so much different, we will use the same population and urbanisation rate in this study for different scenarios. We assume that the population peak will be 1600 million and which will take place in 2050. After 2050 the population will decrease slowly and decrease to 1500 million in 2100. For urbanisation rate, it will increase to 70.0% (the level of the US in 1970s) in 2050 and 95% in 2100. See table 5.5.

Table 5.5: Forecast on population and urbanisation in China in the future (this study)

	2000	2010	2020	2050	2100
Total population (million)	1280	1379	1483	1600	1500
Urban (million)	403.2	517.1	667.4	1120	1425
Rural (million)	876.8	861.9	815.6	480	75
Urbanisation rate (%)	31.5	37.5	45.0	70.0	95.0

5.3.2 Economy growth and industrial structure change of China

5.3.2.1 Economic growth

During the 20 years (1979~1998), the average annual GDP growth rate of China was as high as 9.7%. It is should be noted that it is difficult to keep the same high growth rate in the next 50 years. Nevertheless, the Chinese economy will keep a relative high growth rate during the next 50 years, because system innovation will improve efficiency, structure adjustment will create new point for economic growth, increase of income and consumption per capita will bring about bigger development potential. The market will expand because of industrialisation, urbanisation, internationalisation and west China development. Export and import will expand because of the entering into the World Trade Organisation (WTO).

As for population, many organisations forecasted the economic growth rate in China during the next 20 years, see table 5.6.

Table 5.6: forecast on economic growth rate in China (% per year)

	2001~2010	2011~2020
AIM	7.5	6.5
CAS	8	7
CASS	8.2	
ADB	7	6
WB	8	6.5
UNEP	7.5	6.0
ERI	7.2	6.0

5.3.2.2 Industrial structure

Table 5.7 shows the different forecasted results of industrial structure in China in future. As discussed earlier, the share of the service sector in China is currently rather low. According to the situations of the past 20 years, the share of tertiary industry increased from 23.7% in 1978 to 32.9% in 1998, increasing 0.5% per year. We expect this trend to continue in the future. The share of secondary industry is basically stable, which was 48.2% in 1978 and 48.7% in 1998. This means that China is still in the industrialisation stage, the growth of GDP relies mainly on the growth of secondary industry. However, according to the experiences of developed countries, the share of secondary industry of China should decrease gradually. The share of primary industry decreased rapidly during the past 20 years, decreasing from 28.1% in 1978 to 18.4% in 1998. It is estimated that this trend will continue.

According to the above analysis, in the present project we will use the forecast of ERI. China Economic Herald published the paper of Junlu Jiang, from the State Development Planning Commission (SDPC) on March 31st, the paper concentrates on the issues in the principles of formulating 'Tenth-five year' Planning. The paper points out that the average ratio of industries will be 14:40:46 during 2001~2005. This is a higher requirement on industrial structure change, namely, decrease the share of secondary industry and increase the share of tertiary industry.

Table 5.7 Forecasted industrial structure of China

	2000			2010			2020		
	1	2	3	1	2	3	1	2	3
CASS	17	51.7	31.0	14	51.5	34.4	11	50.2	38.3
SDC	14.73	47.68	37.59	9.38	48.96	41.66	6.85	48.35	44.79
ADB	23	44.0	33.0				15	42.0	43.0
WB	16	50.0	34.0				7.0	48.0	45.0
UNEP	18.4	45.16	36.3	12.2	43.36	44.44	8.7	41.0	50.3
ERI	17.0	49.0	34.0	12.0	45.0	43.0	8.5	41.0	50.5

Note: 1 = primary sector, 2 = secondary sector, 3 = tertiary sector.

Table 5.8: Forecasted economic development of China (used in this study)

		1995	2000	2010	2020	2050	2100
C1	GDP growth rate, %		8.0	7.2	6.0	4.0	3.0
	GDP(1995 price), 100 million yuan	58478	85923	171846	307750	998156	4375822
	Primary sector (%)	20.5	17.0	12.0	8.5	5.0	3
	Sec. sector (%)	48.8	49.8	45.0	41.0	38.0	30
	Tertiary sector (%)	30.7	33.2	43.0	50.5	57	67
C2	GDP growth rate, %		8.0	8.0	7.0	4.5	3.5
	GDP(1995 price), 100 million yuan	58478	85923	185501	364908	1366696	7632897
	Primary sector (%)	20.5	17.0	11.0	7.0	5.0	2
	Sec. sector (%)	48.8	49.8	44.0	40.0	35.0	25
	Tertiary sector (%)	30.7	33.2	45.0	53.0	60.0	73

Based on the above analysis and considering the industrial structure change in the industrialised countries, we have constructed two scenarios, C1 and C2 for this study, which are the base of assessment on strategic options for sustainable development of energy and environment (See table 5.8). On the whole, the industrial structure of China in 2050 will be close to the level of OECD countries in 1980s. The share of service industry in C2 is higher than that in C1. The share of primary and secondary industry will further decrease and the share of service industry will further in 2100. Generally speaking, C1 is a scenario that social and economic development is close to the Chinese government's planning and C2 is a higher growth scenario.

Private consumption
Table 5.9 shows the share of private consumption in GDP of selected countries.

Table 5.9 The share of private consumption and total consumption in GDP, %

	China		Japan		US
	Private consumption	Total consumption	Private consumption	Total consumption	Total consumption
1970	54		58		
1975	52		60		
1980	54	66	59	69	81
1985	56		59		
1990	51	61	58	67	85
1995	48	59	59	70	84

Sources: World Bank & International Statistical Yearbook, 1999

Because of the tradition of Chinese, the share of private consumption both in GDP and in total consumption of China is relatively lower if it is compared to other countries. Recently, the share of private consumption further decreased. However, along with the implementation of reforms and the adjustment of industrial structure, the share of private consumption both in GDP and in total consumption is expected to increase in the future. We assume that the similar situations of Japan in 1990s will take place in China in 2050. Table 5.10 shows the assumption of the share of private consumption in GDP of China assumed in this study.

Table 5.10 The share of private consumption in GDP of China in the future (this study)

	1995	2000	2010	2020	2050	2100
Private. Consumption (% of GDP)	48	48	52	55	60	60

6. Results of the baseline scenarios for China

In This part, we will show some of the simulated results of the two baseline scenarios, such as energy demand, energy consumption structure, fuel prices and investment in energy, CO_2 emissions, and make a comparison of some indicators between China and the world.

6.1 The A1b-C Scenario: an 'open' China in a globalised world

In this scenario, the population of China will reach a peak of 1.6 billion by the middle of this century then decrease to 1.5 billion by the end of this century. Per capita GDP will reach US$ 10600 and 43000 in 2050 and 2100, respectively. Industry structure follows the way of developed countries. The share of service will increase rapidly and at the same time the share of agriculture and industry will decrease. For the details, see chapter 5.

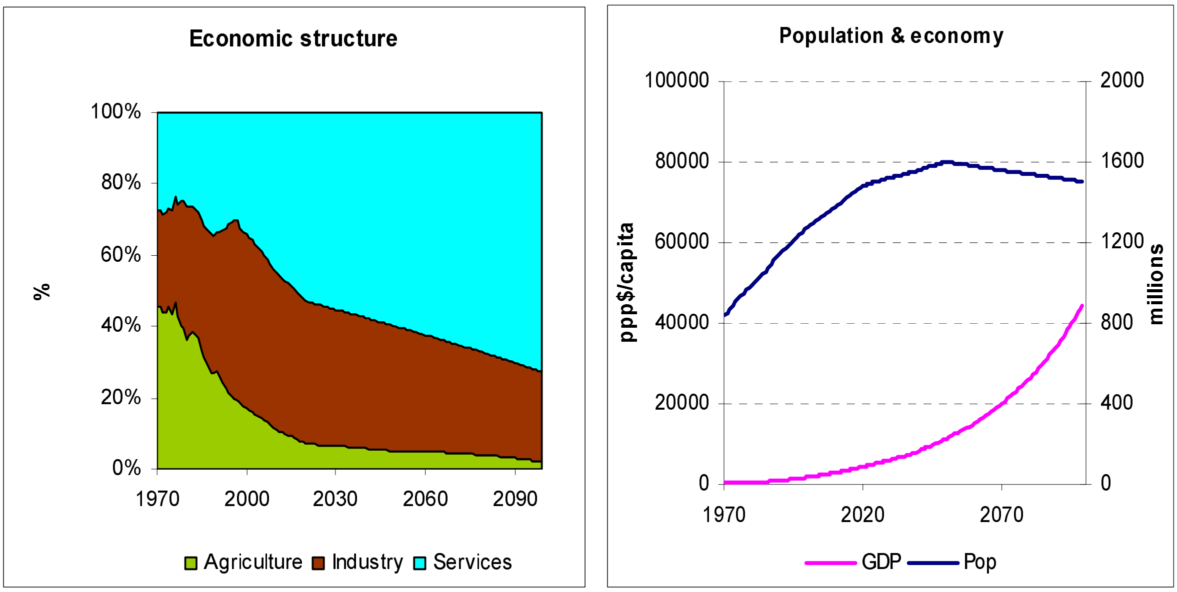
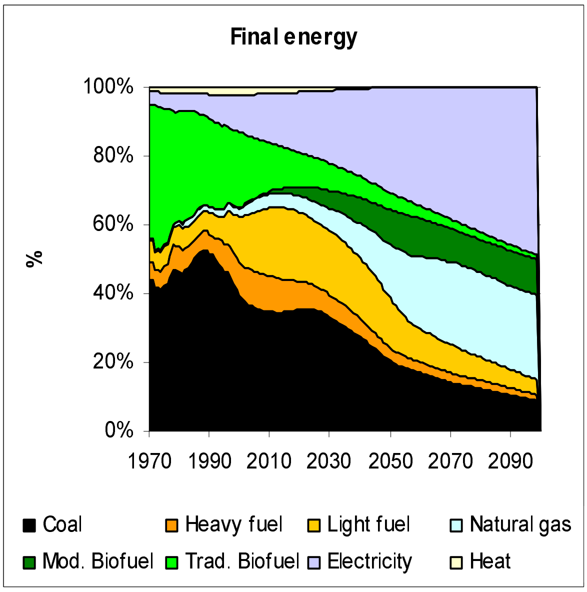


Figure 6.1 population, GDP (left) and economic structure (right)

As a result of economic growth and the orientation towards 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 China 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 by commercial fuels as a consequence of the 'modernisation' 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 6.2).



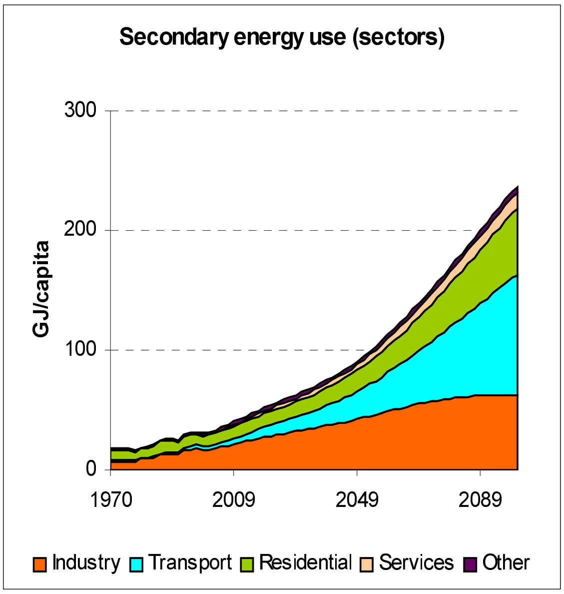
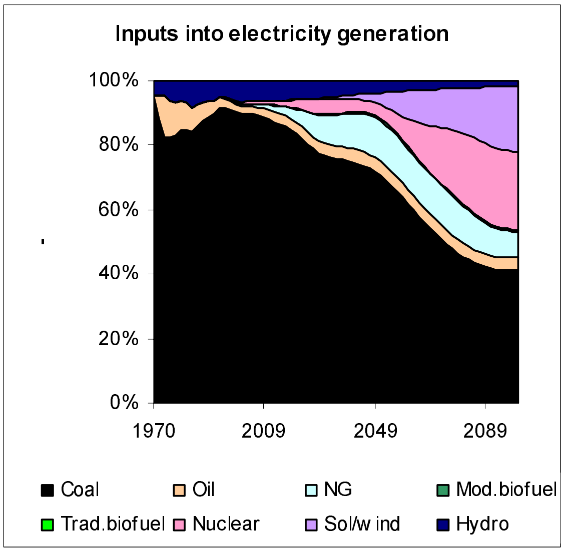


Figure 6.2 Final energy use and secondary energy use by sector

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.

Combining end-use energy consumption and the inputs into electricity production in the model leads to a primary energy use as indicated in Figure 6.3 (right-hand graph), which shows expectations in primary energy use in China continuing to increase at growth rates similar to those in the past. Gradually, energy use will become less dominated by coal.



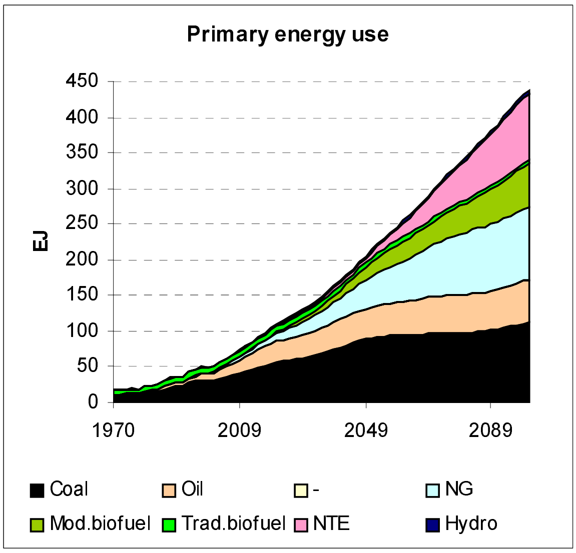


Figure 6.3 Inputs into electricity generation (left) and primary energy use (right)

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. Oil imports will continue to rise. Along with the development of infrastructure for natural gas, natural gas import will increase rapidly after 2010. 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 (figure 6.4).

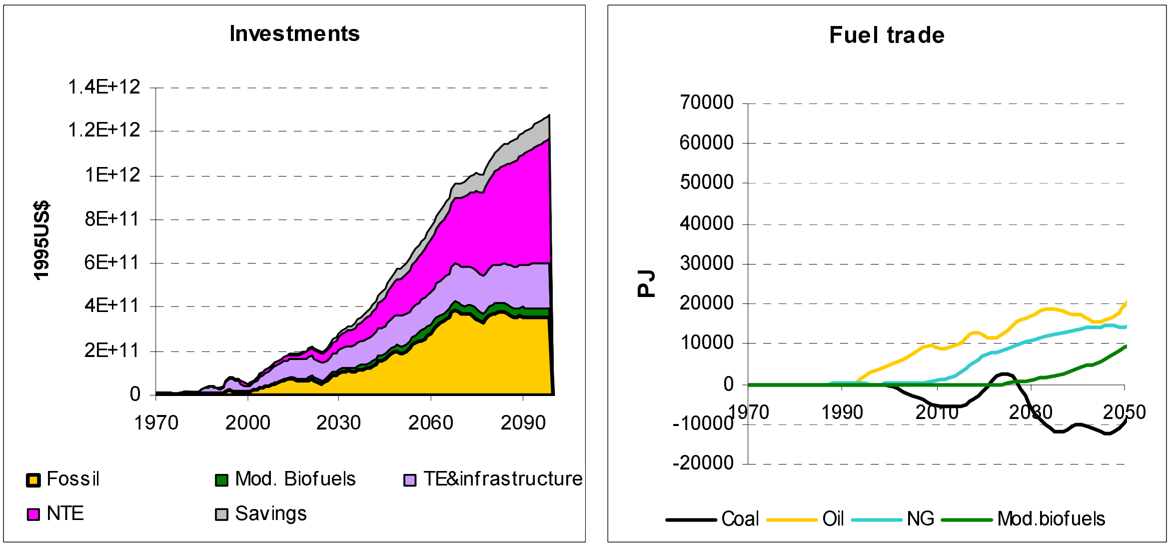


Figure 6.4 Fuel trade (left) and investment in energy (right)

Investments in energy will increase gradually; they will reach about 1995US$200 billion in 2020 and increase to 1995US$520 billion in 2050 and 1995US$1660 billion in 2100 (figure 6.4). In the first half of the century, most of these investments will be in fossil-fuel based electric power generation. In the second half, non-thermal electricity (nuclear and/or renewables) takes over. The reason is that on the one hand, fossil fuel resources get more expensive with time, while, on the other, technological advancement will enable China to develop non-thermal electricity. 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% 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, like production costs, taxes and transport costs, will have an impact on fuel prices. Production costs are the net result of two factors: depletion and innovation. 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 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 because of its abundance (figure 6.5).

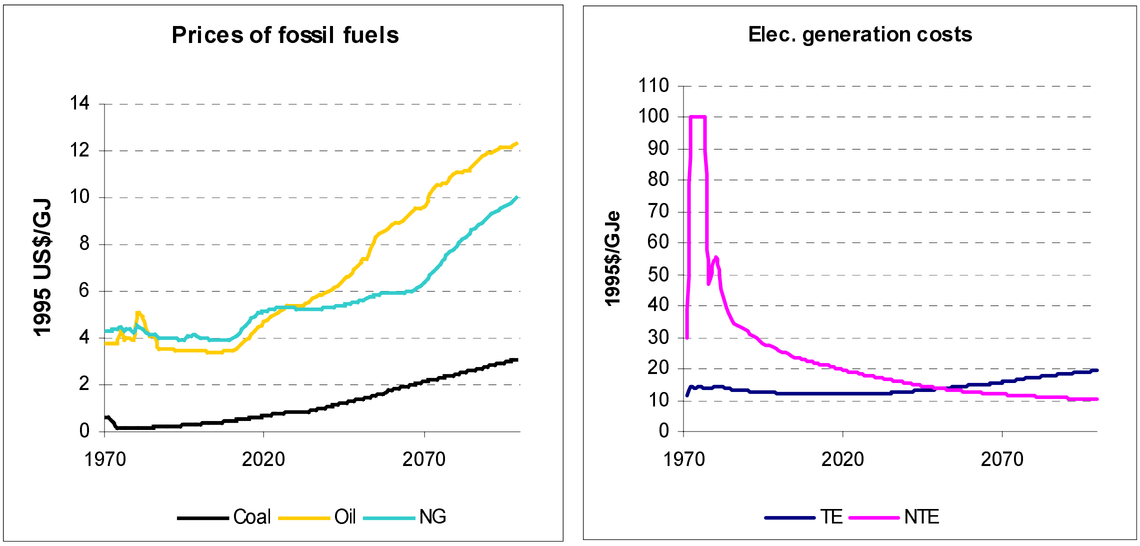


Figure 6.5 Prices of fossil fuels and electricity generation costs

6.2 B2-C scenario: China geared to solving Chinese environmental problems

In this scenario, the population of China will follow the same the track of A1B-C scenario. Per capita GDP will reach US$ 9000 and 28000 in 2050 and 2100, respectively (figure 6.6). Industry structure follows the way of developed countries. The share of service will increase rapidly and at the same time the share of agriculture and industry will decrease. On the whole, GDP increase and economic structure change will take place at a lower rate compared with A1B-C scenario. For the details, see chapter 5.

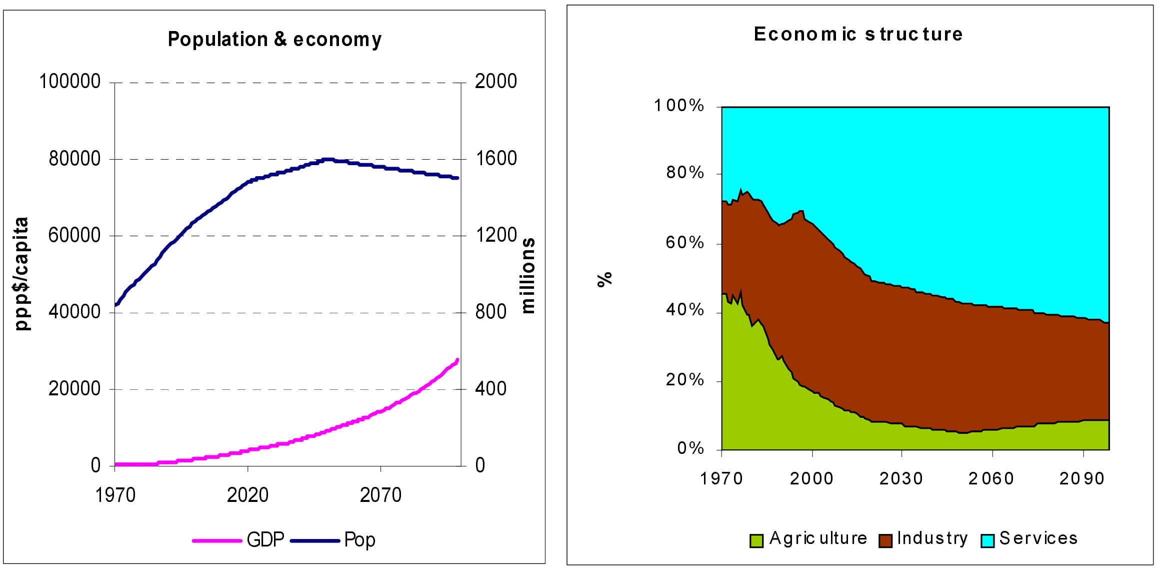
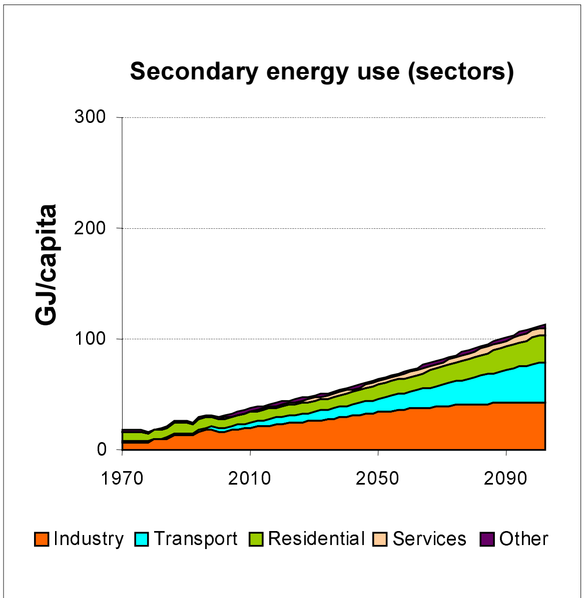


Figure 6.6 Population, GDP and economic structure under B2-C scenario

The main 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 A1b-C scenario. The structure of end-energy use per sector follows a similar path to that in the A1b-C scenario: i.e. the share of industry decreases while the share of transport increases. However, the changes are slower than that in A1b-C scenario. The share of transport will increase to about 20% in 2050 and 32% in 2100. Although the share of industry will slowly decrease to 38% by the end of the century, it will still be the largest energy consumer. Energy use in the residential sector increases only slowly, as people will use less low-efficient traditional biomass and more high-efficient and convenient energy.

The combination of a stabilising population, an exponentially growing income, an increasing share of the service sector and an orientation on regional sustainability causes primary energy demand to stabilise gradually at about four times the 1995-level by 2100. However, the regional orientation makes coal for the coming decades the most important supply option: coal use more than doubles to 80 EJ by 2050. In the second half of the century, natural gas becomes more dominant as the large unconventional reserves are taken into exploitation. Industry remains for most of the century the largest energy user, but this is partly due to the inclusion of energy for freight transport in this sector. Energy for transport is the fastest growing energy user. The fraction of electricity in final energy demand keeps growing whereas the fraction of traditional fuel use keeps falling, both a reflection of the modernisation process (figure 6.7). The orientation on indigenous supply options and the limited low-cost oil and gas reserves allow a gradual penetration of biomass-derived fuels – in fact, these 'modern' biofuels are replacing part of the traditional fuels in rural areas.

Regarding the structure of primary energy demand by energy carrier, the share of natural gas, modern biomass, solar and wind energy will increase. However, compared to A1b-C scenario, China will depend on domestic energy resources, which are dominated by coal. Thus, coal will continue to be the most important energy source in China throughout the century even though its share will gradually decrease to 53% in 2050 and 34% in 2100. The structure of fuel for power generation also shows a similar situation, although somewhat later. Fuel trade is smaller 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.



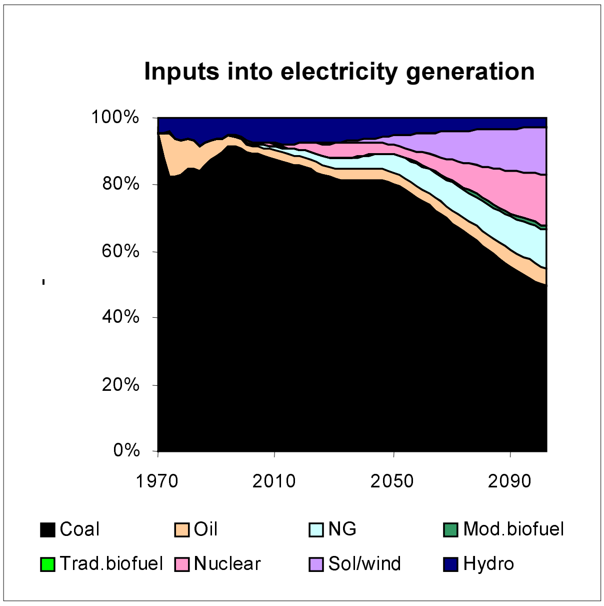


Figure 6.7 Changes in composition of final energy demand (left) and the generation mix in the electricity generation sector (right) in the B2-C scenario (NG = natural gas; Sol = Solar)

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 A1b-C scenario; fossil fuel will lose its share while non-thermal electricity, NTE (nuclear and/or renewables) will gradually gain a larger share.

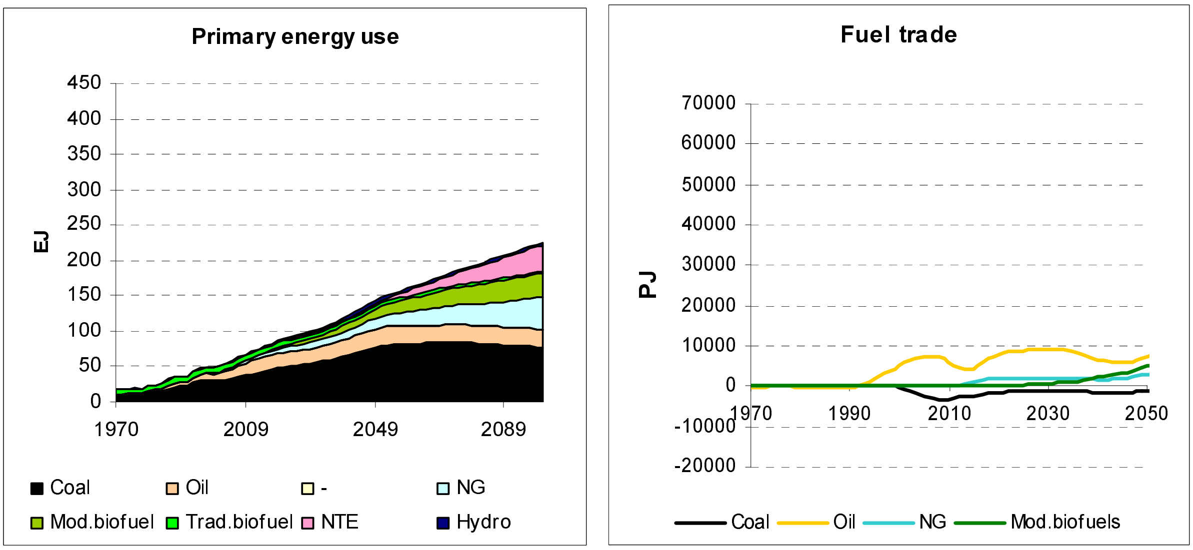


Figure 6.8 Changes in primary energy use and fuel trade in the B2-C scenario (NTE = Non Thermal Electricity; NG = natural gas)

Fuel price development shows one remarkable difference. In the B2-C scenario, China depends for a bigger part on domestic energy resources. Due to depletion of domestic oil and natural gas resources in the late 2010s, their prices and especially the price of natural gas will therefore rise sharply. As a result, the differences 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 (Figure 6.9).

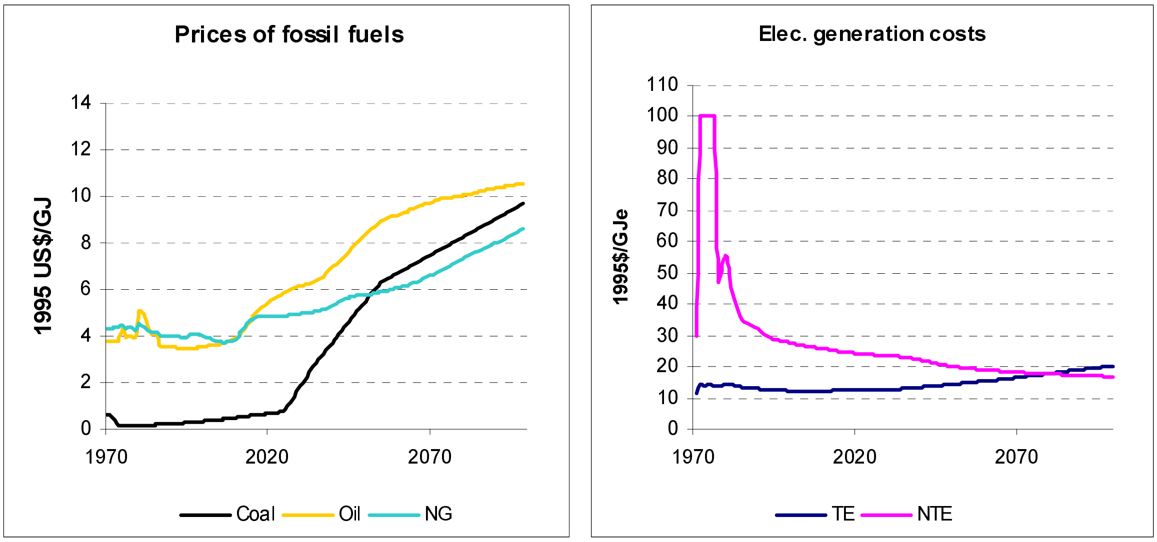


Figure 6.9 Prices of fossil fuels and electricity generation costs in the B2-C scenario

6.3 Carbon dioxide emissions

In 1990, carbon dioxide emissions of China were 0.68 billion tonne carbon in 1990, which rapidly increased to 0.90 billion tonne carbon in 1995. The energy-related carbon dioxide emissions can be calculated directly from the energy consumption and production profiles. Between 1996 and 1999, China experienced a decrease in the energy use as a consequence of a set of short-term trends (reduction in economic growth, improvement in coal quality) and longer-term trends (e.g. efficiency improvement). We have captured some of the relevant factors in the model, for example, by 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 important 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 terms of Carbon emissions per capita, it is about 0.7 tons in 1995, which will increase to 2.4 tons in A1B-C scenario and to 1.7 ton in the B2-C scenario in 2050.

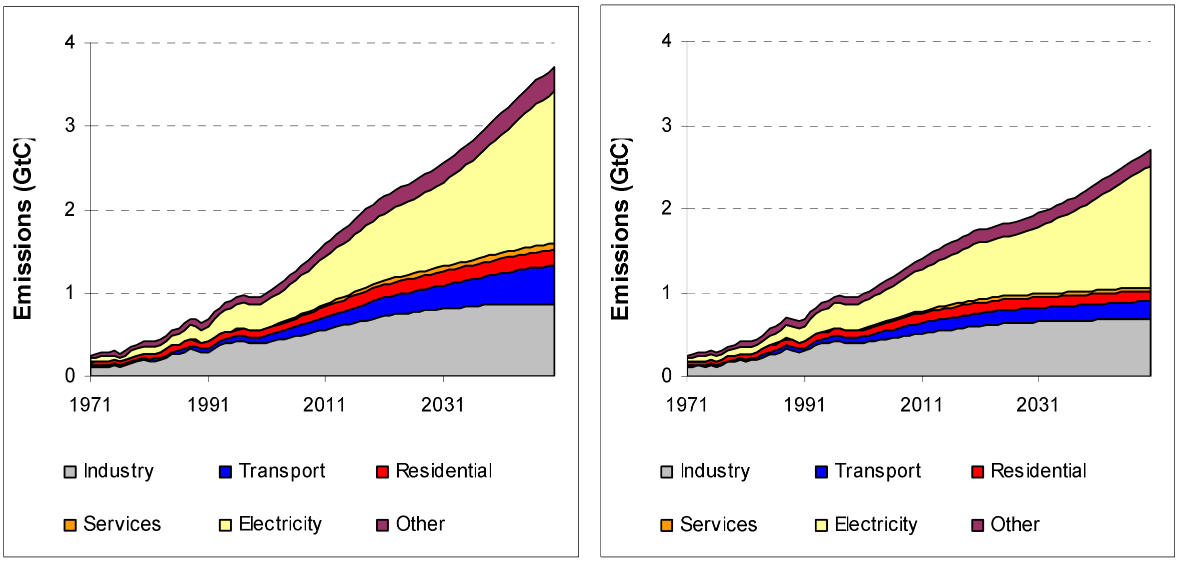


Figure 6.10: Changes in carbon dioxide emissions in A1B-C (left) and B2-C (right).

6.4 Alternative scenarios: A1F-C and B1-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 interesting here. These are the B1 scenario, a scenario based on globalisation but time-oriented towards sustainable development, and the A1F 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.

The B1 scenario describes a world dominated by high levels of environmental and social consciousness and successful global co-operation. 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, but service-oriented lifestyle (also the Western countries will move in this direction in B1). In such a scenario we see a rapid improvement in efficiencies. The result is a decline in energy intensity of 40% compared with that in A1b-C. The 2100 energy consumption of 70 GJ per capita (see Figure 6.11) is very low compared to the current OECD average of 150 GJ. However, it is comparable to the OECD average in that year; 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. The extensive use of solar and wind power also means that technology development with regard to these sources will be swift, enabling further penetration of these renewables.

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

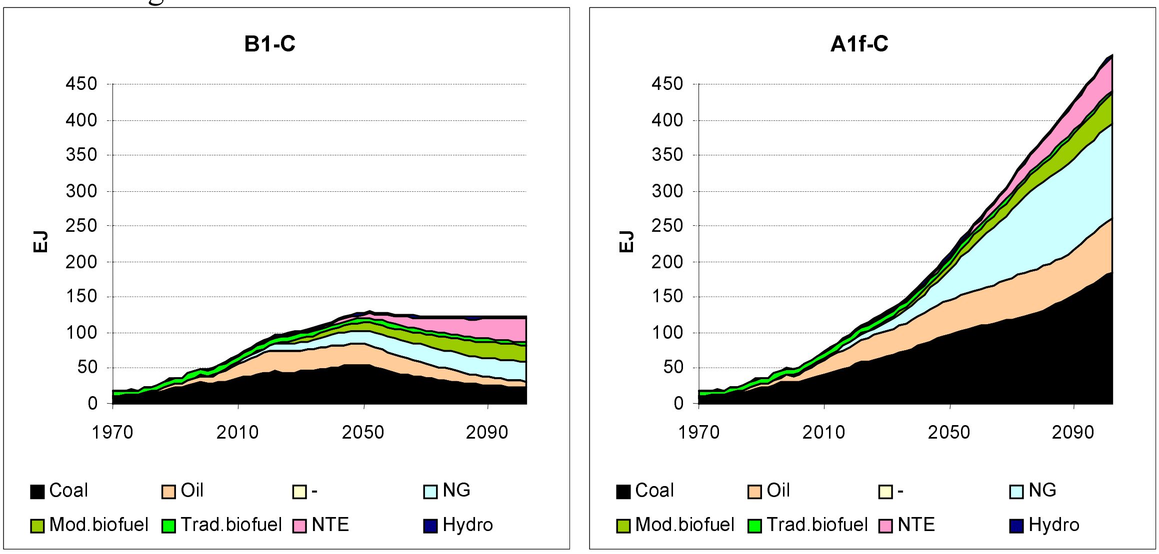


Figure 6.11: Primary energy use in the alternative B1-C (left) and A1F-C (right) scenarios Note: NTE = Non Thermal Electricity (Nuclear, solar, wind)

Figure 6.12 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. The main reasons for this are the high energy use per capita and the 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 A1b-C (reflected in a higher carbon value). Finally, the B1-C scenario sees emissions doubling in the first half 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.

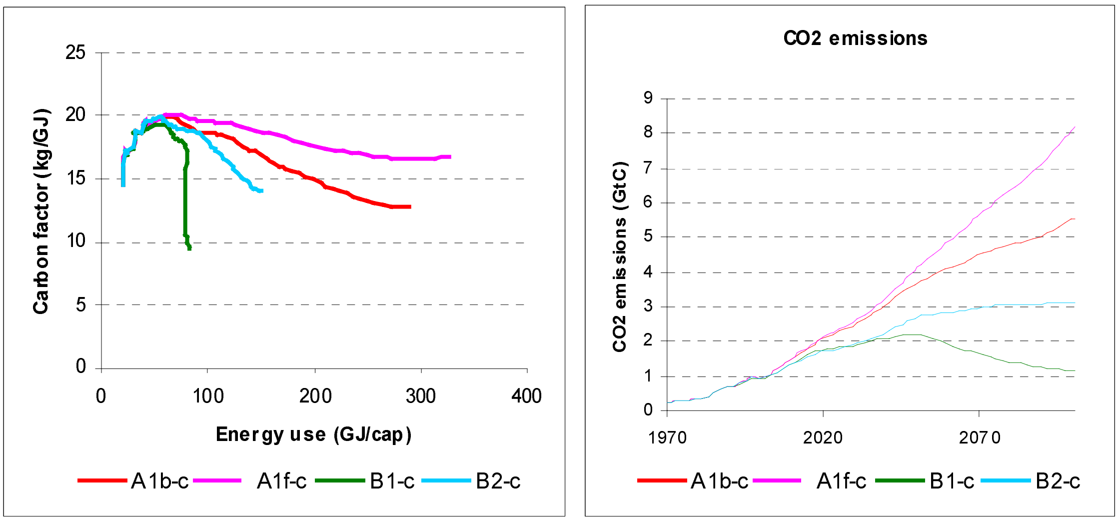


Figure 6.12: Trajectory of energy use (GJ per capita) with carbon factor (tC/GJ) (left) and CO_2 emissions (GtC)(right) in the four scenarios developed for China in this analysis.

6.5 China's position in the world

In the last decade, we saw the contacts between China and the outside world being strengthened. It could be interesting to compare the results of our scenarios with some of the other regions of the TIMER-IMAGE model (see Table 6.1).

Starting with income, China's GDP per capita (even in Purchasing Power Parity) is low compared to many of the OECD regions. It was about US$357 in 1990 and about US$578 in 1995, which was only one-tenth of the world average and one-fortieth of the USA's. The GDP per capita in 2050 will, in the A1b-C scenario, be close to the current level of OECD countries – and only slightly lower in the B2 scenario.

The energy intensity statistics show the energy intensity (MJ/ppp$) in China to be considerably higher than the other regions (27.8 MJ/ppp$ vs. 11.4 MJ/ppp$ in the USA and 7.4 MJ/ppp$ in Western Europe). This is, for example, caused by China's reliance on heavy industry and energy inefficiency in industry and electric power generation. Energy intensity is expected to decrease in all regions although at different rates. In the A1b-C scenario, rapid technology transfer spurred by free trade allows China to close the gap in energy efficiency to OECD countries by about a factor of 2. In the B2-C scenario, environmental awareness also allows for decline in energy intensity, resulting in a similar energy intensity level.

The carbon factor indicates carbon emissions per unit of energy consumed and is a function of the energy mix. The China carbon factor is fairly high as a result of its heavy reliance on coal. The open character of the A1b-C scenario allows the country to decrease its carbon factors to normal levels among OECD countries. Western Europe and the USA are, in turn, able to decrease their carbon factors due to further penetration of natural gas and renewable energy.

Both scenarios show that Chinese carbon dioxide emissions will be close to the USA's in 2030 and further increase to 2.7 billion tonne carbon under B2-C and 3.8 billion tonne carbon under A1b-C in 2050. It should be noted, however, that the carbon dioxide emissions in China per capita are still very low. In 1990, emissions in China per capita were 0.6 tonne, only about half of the world average and one-tenth of the USA's. This increased to 0.74 tonne in 1995, about 70% of the world average. It 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.

Table 6.1: 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
	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$1995)	China	357	578	1,711	4650	10,600	1,574	3,728	7,720
	USA	24,727	26,316	39,517	53,490	73,660	38,108	47,484	58,873
	Western Europe	20,122	21,636	30,227	45,097	63,212	28,765	37,953	46,533
	World	4,705	4,830	6,531	11,208	21,454	6,178	8,857	13,202
Energy consumption per capita (MJ)	China	31.3	39.0	57.5	88.6	133.6	51.4	66.7	91.6
	USA	303.1	308.5	379.3	416.4	426.3	358.3	333.2	290.4
	Western Europe	143.5	144.3	193.3	241.9	273.6	177.6	179.7	166.3
	World	66.0	64.8	82.8	118.8	157.3	76.7	87.9	95.0
Energy Intensity (MJ/ppp$)[9]	China	34.4	27.8	18.0	13.4	10.7	17.2	12.1	9.8
	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	6.0	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
	USA	18.4	18.3	17.9	16.9	15.0	17.7	15.3	12.5
	Western Europe	17.4	17.0	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	16.0	14.1
CO_2 (billion tonnes C)	China	0.7	0.9	1.6	2.6	3.8	1.4	2.0	2.7
	USA	1.4	1.5	2.1	2.5	2.5	1.9	1.8	1.4
	Western Europe	1.0	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 C)	China	0.6	0.7	1.1	1.7	2.4	1.0	1.3	1.7
	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	2.0	2.4	1.3	1.4	1.3

6.6 Local environmental consequences

The current level of sulphur emissions in China (around 18 Tg S) contributes to both regional air pollution (in particular, acidification) and urban air pollution. Therefore, we concentrate in this section on sulphur emissions from the baseline scenarios. In all scenarios, we have assumed that the Chinese government will intensify its effort to reduce sulphur emissions. However, the level of effort paid is different – and obviously also the energy mix is different. In Figure 6.13 we have plotted the carbon emissions of the scenarios against the sulphur emissions. The main differences in emissions between the four scenarios are caused by the high level of environmental protection in B1-C and B2-C (moving away from coal in the former, clean coal in the latter) and the less strict protection levels in A1b-C and A1F. In

[9] 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.

addition, however, we can see that sulphur emissions are also a function of the changes in energy mix – B1-C has fewer sulphur emissions than B2-C; A1b-C has fewer emissions than A1F-C. In other words, lower carbon emissions coincide with lower sulphur emissions. The sustainability oriented B1-C scenario benefits in particular from this.

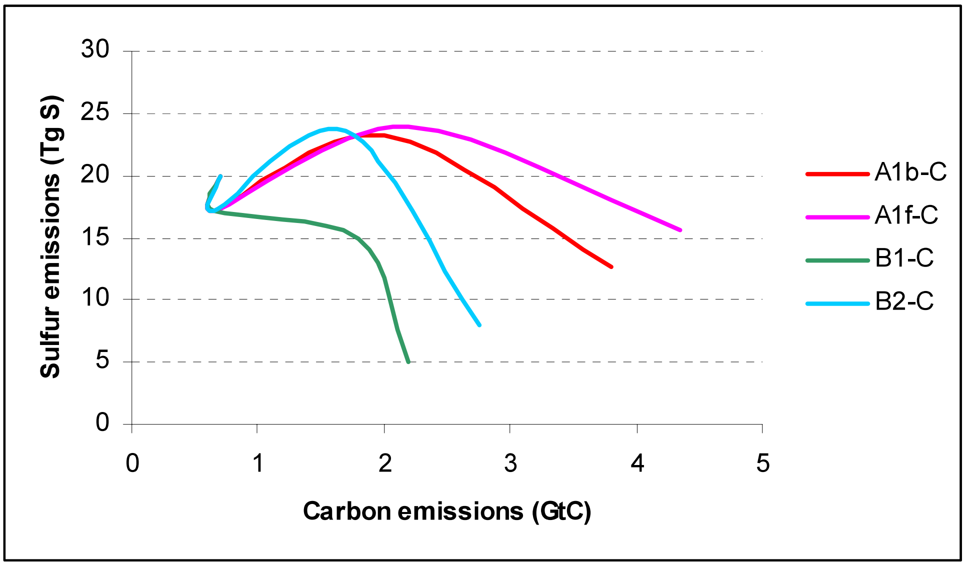


Figure 6.13: Carbon and sulphur emissions under four scenarios.

6.7 Comparison with other (sub)projects

The scenarios presented here can be compared to other baseline scenarios. A large set of baseline scenarios by different (international) modelling teams was recently presented at a modelling workshop in Beijing (see also logan, 2000). Both the A1B-C and B2-C scenarios lie within the range drawn up by these baseline scenarios which ranged from 1.2 to 2.8, 1.8 to 4.2 and 1.8 to 6 GtC for 2030, 2050 and 2100, respectively. For the first 50 years both A1b-C and B2-C are above the medium projection that can be constructed from the total set of baseline scenarios – reflecting the story lines of the two scenarios (high energy demand in A1B-C and reliance on domestic coal resources in B2-C).

7. Carbon emission mitigation: Policy scenarios for China

7.1 Policy needs for China

In the previous sections we have indicated that baseline development are likely to lead to considerable CO_2 emissions and energy use. In most cases the required reductions, to reach the targets in the UNFCCC context, need action from both developed and developing countries while following the principal in UNFCCC. It is necessary to understand the effects of various possible policy options on GHGs emission reduction compared with the emissions in the baseline scenario. 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.

Table 7.1 Overview of needs and options for mitigation in the different baseline scenarios

A1 family	B1 family	A2 family	B2 family
Needs and options for mitigation: • Climate policy strongly needed • High income and technology level: abundant means for mitigation / adaptation • market-based solutions, e.g. emissions trading; focus on technology • marginalised peoples / areas	**Needs and options for mitigation:** • climate policy needed • high income and technology level: means for mitigation / adaptation • equity-oriented regulation, e.g. graduated tax; • focus on both technology and life-style • compensation for affected peoples/areas	**Needs and options for mitigation:** • climate policy urgently needed • low income and technology level: scarce means for mitigation / adaptation • market-based solutions; • international co-operation ineffective • damage and forced adaptation in many areas	**Needs and options for mitigation:** • climate policy strongly needed • low income and medium technology level: modest means for mitigation / adaptation • equity-oriented regulation • focus on both technology and life-style • compensation for affected peoples/areas

7.2 The context for and content of climate change policies in China

China is presently in a stage of rapid industrialisation, which forms part of a series of simultaneous processes of transformation such as rising income, increasing urbanisation and a decline in the share of the agricultural sector in the economy. Although these societal changes are often associated with a more general process of 'modernisation', there are also various circumstances that are specific for China. Hence, one has to carefully investigate the energy and associated systems in China, as well as the forces at work, if one is to recommend policies to reduce GHG emissions.

Increasingly, the need for a more sustainable development pattern than the one taken by presently industrialised countries, over the last 100 years is felt in the less industrialised regions of the world. This is at least as much a consequence of the perceived local environmental threats as of the possible global consequences of unsustainable practices. Yet, there is a basic motivation for climate policies in China. China has recognised the necessity of climate change abatement action in response to UNFCCC, which was ratified by China in 1992. Climate change could be an important factor for the Chinese government in designing future environmental development in the framework of sustainable development, a fundamental long-term strategy set up by government. Many elements of climate policy could also support such a longer-term strategy in the form of co- or ancillary benefits, as will be shown later on in this section.

The previous section outlined two possible developments in Chinese society over the next decades, our baseline scenarios. Within each of these scenarios, 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. In that sense it might be helpful to look at the story lines developed by the SRES modellers to develop mitigation scenarios based on the global SRES (IPCC, 2001) scenarios. See Box 7.1 for a short summary.

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

- *(Climate change) Policies*: refers to 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, educational campaigns etc.) that are instrumental in implementing and realising the policy measures.

The set of policy instruments can also be subdivided in several clusters. One group consists of economic measures influencing the decisions made on the basis of (relative) costs and prices: taxes, subsidies, loans etc. A second group consists of regulation measures such as appliance labels, building standards, industrial covenants, environmental laws and the like. A third cluster is technology support in the form of Research, Development and Demonstration (RD&D) projects. Finally, there is a fourth cluster of so-called ‘social instruments’ consisting of information campaigns, education, institutional support and the like which attempt to disseminate adequate knowledge and increase environmental and cost awareness.

Box 7.1: Possible policy options and measures in the global SRES scenarios

- The *Al scenario* is well equipped to formulate and implement mitigation strategies in view of its high-tech, high-growth orientation and its willingness to co-operate on global scale, provided the major actors acknowledge the need for mitigation. Market-oriented policies and measures will be the preferred response. New emission reduction technologies from developed countries will enable developing countries to respond more rapidly and effectively if barriers to technology transfer can be overcome.
- In the *A2 scenario*, developing and implementing climate change mitigation measures and policies can be quite complicated in view of the rapid population growth, relatively slow GDP per capita growth, slow technological progress, and a regional and partially 'isolationist' approach in national and international politics. Relatively low-tech measures as limiting energy consumption, and capturing and using methane from natural gas systems, coal mining and landfills might fit the A2 scenario's economic and technological profile.
- In the *B1 scenario*, the options to formulate and implement mitigation strategies are again very promising, in view of its high economic growth and willingness to co-operate on a global scale. The precautionary principle plays a key role in international agenda setting and policy formulation, with governments taking responsibility for climate-change-related preventive and adaptive action. Tightening international standards generates incentives for further innovation towards energy-efficiency and low- and zero-carbon options. Developed regions support the less developed regions in a variety of ways, including transfer of energy-efficient and renewable-energy related technologies.
- In the *B2 scenario,* actions to reduce GHG emissions are taken mainly at a local or regional scale in response to climate change impacts. They have to fit into regional sustainable development or environmental aspirations, as there is limited effective global co-operation. Existing bilateral trade links will foster bilateral technology transfer from OECD countries to some developing countries.

Table 7.3 indicates the various policy options, measures and instruments which we have explored with the TIMER energy model within the context of the two baseline scenarios. A few important features of these simulations with the TIMER model should be noted:

- Population and economic activity trajectories are exogenous and taken from the baseline scenarios without any feedback from the energy, land/food or climate system being taken into consideration. No changes are assumed in some key, story-line related parameters such as the nature of economic output, the conservation supply cost curve and the wages and interest rates. They are taken as fixed characteristics of the story line/scenario.
- The TIMER model is not an optimisation model. It simulates a complex interplay of decisions within the energy system. Hence, the analysis is often based on expert judgements 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 or (China's) position with respect to other world regions.
- 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. The resulting lower demand for electricity reduces the investments in electric power plants. It also causes fuel substitution and an accelerated penetration of non-fossil options which is a positive feedback loop as long as learning-by-doing is still important and no other system forces operate against further cost decreases.

- 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 greenhouse emissions are absent so one has to rely on proxy variables and on story line related interpretations.

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, as Figure 7.1 shows. Sometimes, such other policies – for instance, population, employment, or health – have large impacts on the greenhouse gas emission path and are as such part of the baseline story line and scenario. The figure below should also be a reminder that the baseline scenarios in no way imply the absence of policy. In fact, their development presumes continuation of existent, as well as starting up of new, policies with regard to a wide array of issues, some of which have an indirect impact on greenhouse gas emissions.

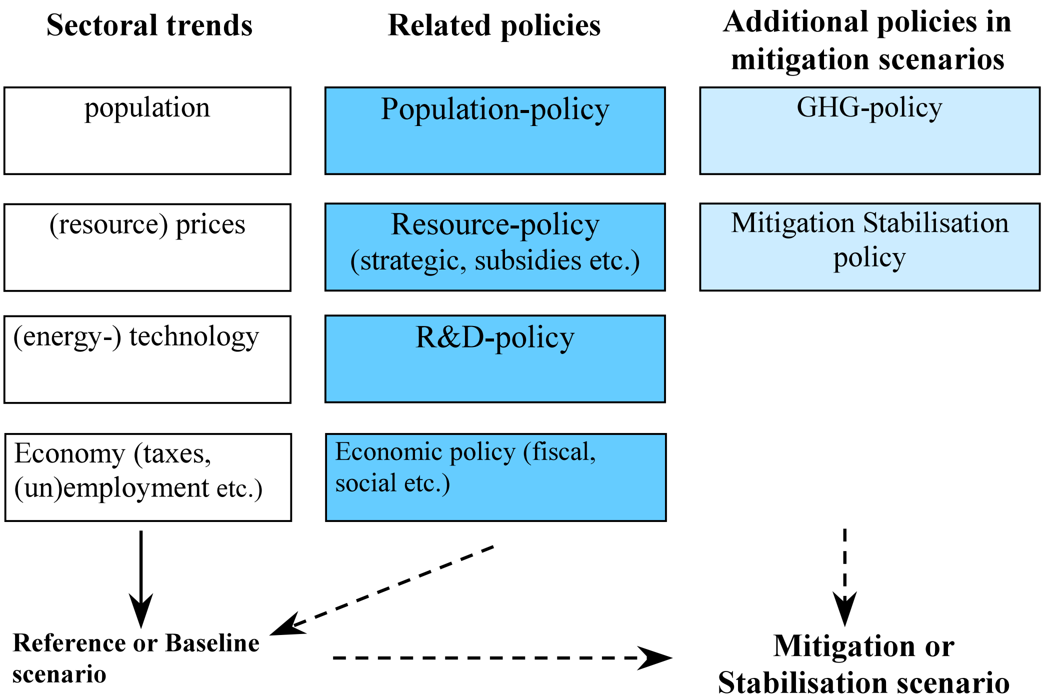


Figure 7.1: Mitigation scenarios as part of a broader context of policies and autonomous trends.

7.3 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; each policy option/measure is evaluated using a set of selected variables: change in investments, in user costs, in balance of fuel payments and in carbon emission.
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, with an evaluation for the variables mentioned under point 2.

We designed 11 policies/measures in this study. Table 7.2 indicates how the policy options have been translated into changes in the model parameters.

Table 7.2 Translation of the policy options into system variables

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.	Introduce a premium factor for coal such as to phase coal out of the residential and service sector by 2020.
3. Influencing market penetration of secondary energy carriers	Reducing the use of coal in the building sector to zero.	Increase the tax on gasoline/kerosene to reach the Western European level by 2020.
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) options including Integrated Gasification Combined Cycle	All new coal power plants from 2010 onwards are highly efficient.	Change the efficiency of coal power plants.
6. Reduce 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 the 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.

7.3.1 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 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 get an indication of the possibilities of other instruments. In particular, instruments such as emissions trading and the Clean Development Mechanism (CDM) which also attach a price to carbon emissions is, in modelling terms, more-or-less equal to a carbon tax. With TIMER, application of the tax generates several direct responses in the model:

1. price-induced investments in energy efficiency;
2. price-induced fossil fuel substitution;
3. less use of fossil fuels and changes in the trade patterns of (fossil) fuels;
4. price-induced acceleration of investments in non-fossil options.

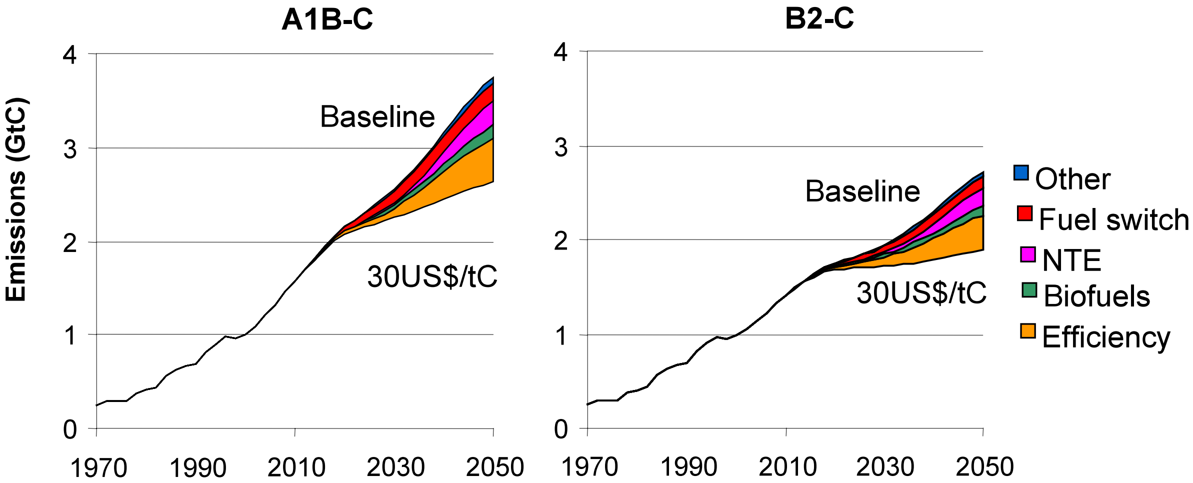


Figure 7.2: Attribution of carbon savings induced by US$30 per tC carbon tax in baseline scenarios.

Figure 7.2 shows that a carbon tax of US$30 per tC (we introduced a carbon tax for 2015 and gradually increased it to US$30 per tC up to 2030; after that we kept it constant) reduces the Chinese carbon dioxide emissions by 30% in both scenarios. Obviously, the absolute amounts differ: about 1 GtC in 2050 in A1B-C and 0.8 GtC in B2-C. To show the contribution of various reduction options, we have allocated all avoided carbon emissions to four different clusters of options: 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[10]. In the first 15 years after the introduction of the tax in the A1B-C scenarios, reductions are dominated by 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 being 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 section.

We can explore the impact of other taxes and 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 7.3 shows the response in two regions (China and Western Europe) for a hypothetical carbon tax introduced in 2000 for two different sight years, 2010 and 2030. The figure shows that significant emission reductions can be achieved in China at relatively low taxes – certainly in comparison to Western Europe. The figure also shows that significantly larger emission reductions can be achieved in 2030 with the same energy tax as in 2010. This is a function of two important mechanisms within TIMER. First of all, delays within the

10 It should be noted that the allocation, particularly the order, would depend somewhat on the methodology chosen. Here, first energy savings have been allocated, next 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.

systems in terms of capital turnover and response time prevent the system from responding immediately to price pressure. For instance, in the electric power generation sector the lifetime of most power stations is more than 30 years. 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.

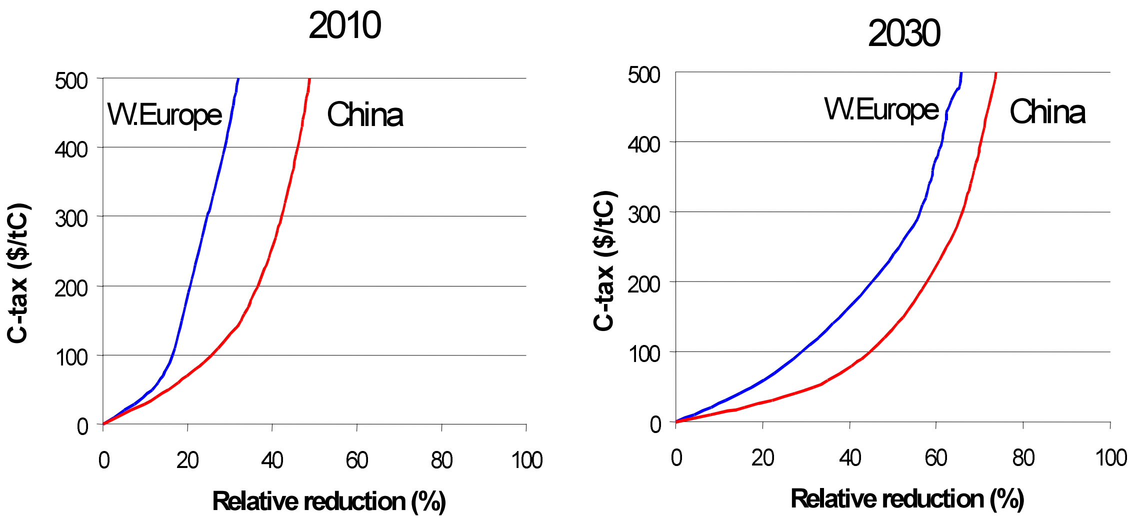


Figure 7.3 Relative emission reduction as a function of carbon tax applied for 2010 and 2030 in scenario A1b-C.

The comparison of the carbon tax response curve of the two regions can give us some idea of the potential for meeting the required emission reductions of Annex-1 countries through actual reductions in non-Annex-1 countries using the so-called CDM instrument. Under the Kyoto Protocol, Western Europe has to reduce its emissions by about 20-30% compared to the baseline. Domestic reductions according to TIMER would require measures to be taken using a carbon value in the order of US$ 200-300 per tC. It should be noted that only reduction options in carbon dioxide emissions in the energy system have been taken into account for this – thus, costs can be significantly lower as there are several relatively cheap mitigation options for other greenhouse gasses. Trading among Annex-1 countries can also significantly reduce these costs. Some current European studies expect that the final carbon price will be around US$20-50 per tC. In China, projects corresponding to a shadow carbon price of US$20-50 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 very attractive for CDM projects.

7.3.2 Carbon emission reduction: policy options and measures

To get a better idea of the potential impacts of different policies in China, we have implemented a series of modelling experiments. In most cases we have chosen 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.

Table 7.3 Overview of policy options/measures, instruments and applicability

Policy measure	**Possible policy instruments**	**Applicability** A1b-C	**Applicability** B2-C	**Implementation explored in modelling experiment**
1. Incentives for energy-efficiency investments	• 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	• 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 the current Western European tax level for oil and gas.
3. Influencing market penetration of secondary energy carriers	• 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	• 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 are highly efficient.
6. Reduce 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	• technology and emission standards • portfolio standards / renewable energy obligation • institutional reforms • RD&D projects • Investments	++	+	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 generation		++	++	The 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 implementable potential of 378 GW.
10. Accelerating the penetration of biomass-derived fuels	• RD&D projects • tax exemption / subsidies to farmers • low/zero-interest loans • portfolio standards / renewable energy obligation	+	+++	Overrule market dynamics with expansion targets; 10% market share in oil/gas market in 2020 and 20% market share in 2050.

Policy measure	Possible policy instruments	Applicability		Implementation explored in modelling experiment
		A1b-C	B2-C	
11. Carbon taxation inducing a series of responses	• carbon tax on fuel use in all sectors	++	++	Implementation of a US$30 carbon tax.
Not explored in model experiments				
Small-scale decentralised electricity generation: • cogeneration • solar, wind, mini-hydro, biomass	• RD&D projects • low/zero-interest loans • high payback rates to grid for distributed generators • institutional reforms	-	++	
Accelerating the availability of natural gas by opening up import, construct infrastructure etc.	• bi/multilateral co-operation • natural gas exploration and exploitation	+++	+	
Carbon removal and storage for large coal-fired power stations	• emission standards	+	-	

Table 7.4 and 7.5 show the 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 characterised along four axes for an overall evaluation:

1. effectiveness in terms of carbon mitigation: fraction reduction with respect to baseline;
2. financial feasibility: fraction increase in energy system investments as fraction of overall investments in the economy;
3. political feasibility: fraction change in user costs as fraction of GDP or consumer expenditures;
4. strategic consequences: change in the dependency on imported fuels as a fraction of total primary energy use and/or the changes in total net costs on imported fuels.

Table 7.4 Introducing policy options/measures in China using the A1b-C baseline scenario

Measure / Instrument (c.f Table 7.3)	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

Table 7.5 Introducing policy options/measures in China using the B2-C baseline scenario

Measure / Instrument (c.f. Table 7.3)	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	-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 electricity								
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 distribution	-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

The tables show most of our explored policies to have similar results and dynamics in both baseline scenarios. It is interesting to see that many options differ strongly in the type of response within the system.

One of the most effective and promising options in reducing carbon dioxide emissions is clearly improvement of energy efficiency, reducing C-emissions here by 10-15%. The option, however, requires considerable investment from end-users whom might be covered by subsidies or soft-loans. An important advantage of this policy is its ability to sharply reduce the reliance of China on imported natural gas and oil. The energy taxation measures explored (raising or introducing fuel taxes in industry and transport) have a modest impact on carbon dioxide emissions. In particular, the fuel tax in transport has an important ancillary benefit in that it can generate the finance required for investment and maintenance of transport infrastructure. Obviously, the taxes lead to strong increases in user costs. Recycling tax revenues (for instance, reducing the current road construction fee on cars) might compensate some of these costs. At the moment, many of the OECD countries are reformulating their tax policies, lowering the taxes on labour and increasing them on resource extractive activities. There might be a potential here for countries such as China to leapfrog this development. The fuel tax reform leads to a temporary increase of import costs. The impacts of banning coal use from buildings has relatively little impact in overall emissions: most of the coal use in these sectors has already been phased out as result of environmental policies and other trends in the baselines. Nevertheless, further reduction of coal use – where possible, given limited access to other fuel types in rural areas – might have an important ancillary benefits for other environmental problems. Obviously, reduction of coal use leads to larger oil and gas imports.

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 generation. It should be noted that improvement of electricity distribution could further reduce emissions by 1%. The strategy to develop and apply coal-based clean technology such as IGCC could have both environmental and economic benefits, especially if China could become leading in this technology.

In China until 2050, alternatives for fossil fuel in the power sector are likely to remain poor competitors against thermal power plants with large supplies of very cheap coal. This implies that policies aiming to bring down costs of these alternatives (either nuclear, wind or solar) to improve their competitive position are unlikely to be very successful. Additional measures are required, such as long-standing renewable energy obligations or combinations 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 need to be imported.

Finally, as indicated earlier, a carbon tax of US$30 per tonne carbon stepwise introduced in the 2015-2030 period, can induce other measures, which combined, reduce emissions by 30% in both scenarios. It would require considerable additional investments to be made and increase user costs. As the funds raised by the tax itself, in principle can 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%.

7.3.3 Combining different options into detailed 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 combination with others. Here, we will present the construction of a mitigation scenario, calculating the carbon emissions based on a combination of the policy options discussed in the previous sections. We have grouped them into four different categories: 1) end-use oriented measures, 2)measures for fossil-based electricity, 3) additional use of renewables and 4) a carbon tax of US$30 per tC.

Figure 7.4 (left) shows the carbon emission profile for the sequence of these different options with the A1b-C scenario as the baseline. Demand-side measures form a very important part of the emission reductions obtained in these scenarios. If all options/measures are implemented, emissions in the A1B-C scenario are reduced by 50% - leading to a level of 2 GtC in 2050. The type of policies explored in this Chapter should certainly be regarded as feasible.

Figure 7.5 (right) shows the carbon emission profile for the sequence of different options with the B2-C scenario as the baseline. If all options/measures are implemented, the carbon emissions are reduced again by around 50% - and the final emissions come to about 1.3 GtC per year (stabilisation after 2020/30).
A large potential for GHG emission reduction was also identified in other studies (Jiang et al., 1998).

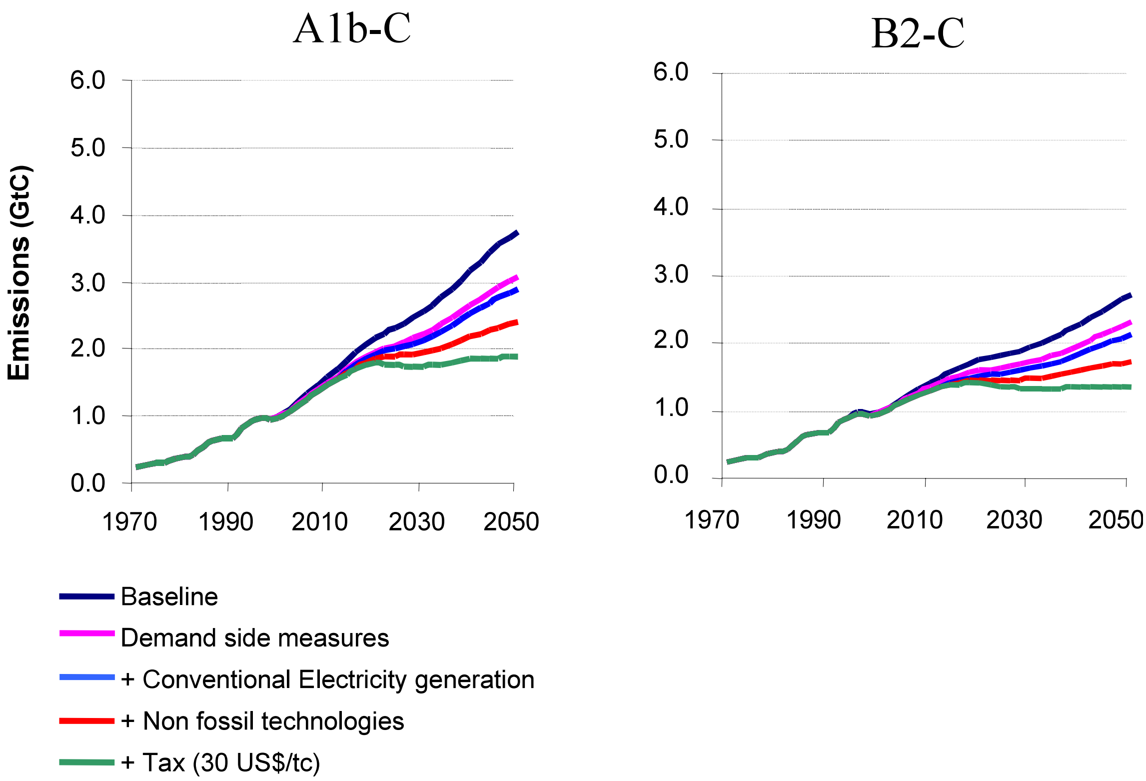


Figure 7.4: Carbon emission reductions achieved by a combination of policy measures.

7.3.4 Comparison with other subprojects

Subproject 6.2 presents an analysis of the determinants of energy consumption in China in the 1985-1995 period. A similar dynamic energy accounting can be done for the scenario simulations with the TIMER model. Figure 7.5 shows the changes in carbon emissions for 1970-1995, 1995-2020 and 2020-2045 for the baseline and the combined mitigation scenario (black bars). In addition, the stacked bars on the left of the black bars indicate which factors have contributed to these changes (c.f. the 'Kaya' equation). The figure clearly shows that not only in the mitigation scenario, but also in the baseline scenario, several factors contribute to emission reductions. This has been discussed in detail on the basis of historical data in Chapter 4 for the 1985-1995 period. For the slightly longer period covered here, the figure shows that 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, in case of 'frozen' energy efficiency. Taking this improvement into account, the net increase is slightly less than a factor 4. In the future too, reduction of energy intensity – based either on deliberate policies to improve energy efficiency or autonomous changes – continues to be an important force preventing the Chinese emissions from doubling or even quadrupling in 25 year periods. Reduction in the carbon factor due to 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. For both the A1b-C and B2-C scenario, the mitigation scenario is successful in actually stabilising emissions after 2020.

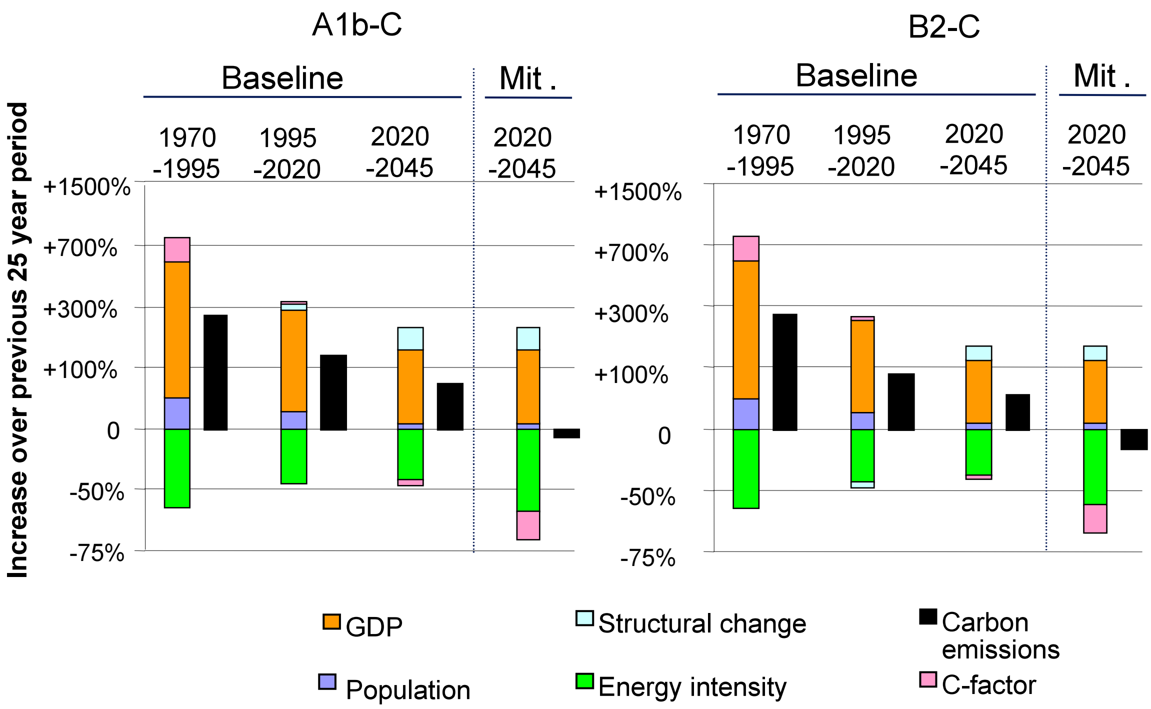


Figure 7.5: Changes in carbon emissions in the different 25-year periods and allocation of these changes to changes in Kaya-factors.

8. Conclusions and suggestions

8.1 Conclusions from scenario analysis

On the basis of previous analyses (including assumptions), the following general insights can be offered:

- Without climate change policies, energy consumption and greenhouse gas emissions in China are likely to increase sharply. The A1B-C and B2-C baselines indicate an increase in emissions between 1995 and 2050 of a factor 4 and 3, respectively. Energy use in transport is expected to increase most sharply – in particular in the A1B-C scenario.
- Coal is likely to remain a dominant energy source in China in the first half of this century. Nevertheless, imports of oil and natural gas will sharply increase – and infrastructure for this needs to be developed. Required investments, in particular in thermal power plants in the first half of the century, are expected to increase sharply – needing sufficient allocation in China's development budget. Investments are expected to be in the order of US$ 500-1000 billion per year in 2050; for comparison, the current investments in Western Europe are about US$ 130 billion.
- Assuming no (forceful) climate policies in other countries in the world, both scenarios are expected to lead to an increase in the global temperature of about 3~4 degrees Celsius by the end of the century. The IMAGE 2.2 model suggests that China will experience temperature increases similar to the overall global temperature increase. It can be concluded that the baseline scenarios will certainly not meet the targets set in the UNFCCC ('stabilisation of greenhouse gas concentrations at levels that prevent dangerous anthropogenic interference with the world's climate system') and that strong climate policies will be needed to meet them. Thus, timely action will have to be taken to address global warming, therefore international co-operation, such as CDM, is now both important and urgent.
- Along with the rapid development in the economy, China's contribution to global carbon dioxide emissions will become more and more important. China's continuous and positive participation will be crucial for addressing climate change. In view of its rapid economic development, the relatively low costs, and the important co-benefits (see further on), China might have the ability to contribute to global carbon dioxide emission reduction sometime in the first half of this century. It should be noted that in the baselines China's share of the end-use energy costs in GDP will decrease from 12% in 2000 to 10 % in 2050 and to 8% in 2100, the current US level is about 8%.
- An orientation on environmental sustainability (e.g. urban air pollution; transboundary air pollution) as assumed in the B2 and B1 scenarios, not only can reduce environmental pressures but also result in lower carbon dioxide emissions. By the same token, control of greenhouse gas emissions can have secondary benefits for other environmental problems, reducing both health and ecosystem impacts (see for instance Wang and Smith, 1999).

There are several promising options for carbon dioxide mitigation in China.

- In the baseline scenarios, energy-related carbon emissions between 2000 and 2050 in China will come mainly from coal use in electricity and industry. The key to reducing China's carbon emissions lies in these two sectors.
- Relatively low costs measures, when compared to international standards, could induce an effective reduction of carbon dioxide emissions. Such carbon taxes can induce several

measures to be taken, such as energy efficiency improvement and switches from carbon-intensive energy to less-intensive or zero-emission energy.

- 'Optimal policies' in terms of CO_2 emission reduction might, in an early stage, focus more on energy efficiency and fuel-switch among the different types of fossil fuels; however, further on in the century non-fossil energy sources should provide the most reductions.
- Our scenarios indicate a strong increase in electricity use in China in the coming decades. Under baseline conditions, coal, possibly clean coal, is expected to remain a dominant fuel in electricity generation on the basis of its very low costs and large domestic resources. There are several specific measures to reduce carbon dioxide emissions in the electric power sector in China.
- One measure is to use more natural gas. Increasing the share of combined cycle to 15% in 2050 can bring about a reduction of 3% in the carbon emissions in 2050. However, increasing natural gas use could lead to more imports.
- Alternatively, coal use could be based on highly efficient IGCC.
- Ambitious hydropower expansion (350GW installed in 2050) can bring about a 2% reduction in carbon emissions in 2050. However, as hydropower in such a case has neared its maximum potential, it will be unimportant for carbon reduction in the second half of the century.
- Other non-fossil-fuels, such as from nuclear, wind and solar energy will be very important to reduce carbon dioxide emissions even further. Slowly non-fossil-fuel based power will become more competitive. However, as electricity in China can be cheaply produced from large coal resources, these options can only play an important role in emissions reduction when they are supported by lasting policy-guided effort (renewable energy obligation targets or carbon taxes).
  The importance of decisions in the electric power generation for Chinese emissions was also found by Zhang (1998), although his study has a much shorter time frame (2010).
- There could be a considerable demand for CDM projects in China. If the world aims at low stabilisation targets, early action offers an attractive pathway (see Van Vuuren and De Vries, 2001). One way to simultaneously reduce mitigation costs in Annex-1 countries and encourage developing countries, including China, to effective and positive participation is to carry out CDM projects. With a carbon price of around US$50 per tC, there is a potential for mitigation in China of 0.2-0.3 GtC. Several other studies dealing (Sands and Kejun Jiang, 2001; Yun Li, 2000) also show a large potential for CDM in China.
- Because of environmental protection and other considerations (such as convenience), we assumed that coal will be phased out in the baseline scenarios in the residential and transport sector. This will, however, need supportive policy actions. The mitigation policies explored further reduce the emissions of sulphur dioxide.
- The analysis of the various options show important trade-offs between different types of policies in terms of investments, increase of user costs, impacts on trade balance, carbon dioxide emissions and other emissions. In particular, policies that rely on a fuel switch from coal to oil and natural gas might be relatively cheap in terms of overall energy costs, but will increase the costs of fuel import. This, for instance, include energy taxation, more use of natural gas in combined cycle power plants and carbon taxes. Energy efficiency measures, on their turn, reduce the costs of fuel import.

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8.2 Policy implementation and suggestions

In the proceeding section, we have discussed the results of our analysis in terms of baseline trends and promising policy measures. These policy measures 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 on the Chinese situation, international experience and the results of our analysis.

- *Combine policy with domestic sustainable development strategy.* Sustainable development is recognised as an important factor in national development for both short- and long-term plans. Agenda 21 for China, announced by Chinese government in 1994, addresses the sustainable path in future, which cover many energy activities. Policy options assessed in this study, such as clean energy utilisation, including natural gas, and nuclear and renewable energy, could well match the targets described in these national plans (see also Zongxin and Zhihong, 1997).
- *Integrate policies with the national energy development plan.* Although energy market reform and regulation restructure is currently underway in China, energy supply will continue to be a key government concern. Environmental and climate policies will need to be integrated with the plans and ambitions set in the national energy development plan. Fortunately, several options that could lead to reduced carbon emissions such as imports of natural gas and oil (A1b-C), implementation of clean coal technology (B2-C) and introduction of renewables (A1b-C/B2-C) are already part of existing energy policies in China. The options discussed for mitigation policies could be seen as a stronger effort in these directions.
- *Develop win–win opportunities*. Much of the potential emission reductions discussed above can be implemented even with finding benefits larger than costs. This means that measures could lead both to economic and environmental benefits. In Chapter 3 examples can be found of policies that were very effective in implementing measures in the past.
- *Use international mechanisms such as CDM, as defined in the Kyoto Protocol*. These mechanisms focus on GHG emission reduction and domestic sustainable development and could help reducing some of the political and financial barriers to greenhouse gas mitigation in China.
- *Match domestic economic instruments*. Tax reform in China started 10 years ago and as result, currently, the tax system is a state of transition. Energy subsidies have been reduced and a fuel tax for transport will be established soon. In most OECD countries, energy taxation has originally been implemented for revenue consideration. In view of the different time period, 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. Moreover, the effectiveness of taxation of environmental policy could be enhanced through double-dividends, as discussed in the IPCC Third Assessment Report (IPCC, 2001).
- *Establish 'green' standards to improve efficiency and stimulate new technology*. For several issues, 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, population growth but also the orientation towards environment and sustainable development values. We have also indicated the potential for emission reduction is considerable, often at low costs. Most options have important trade-offs between different types of policies in terms of investments, user costs, import costs and environmental effectiveness. The following suggestions were found to be very promising:

- Climate change policies should include measures to improve energy efficiency, as the potential for this option is large, measures are relatively cheap – and have considerable co-benefits.
- There are a large number of options to stimulate the development of clean energy sources. This will in particular be important in the electricity generation sector. Policies could include more efficient coal use (e.g. IGCC), more use of natural gas, and the promotion of modern renewable energy.
- It could be very attractive to make full use of international mechanisms for acquisition of technology transfer and know-how.

8.3 Future work

Because of time limits our analysis, as described in this chapter, is still fairly restricted. In the future, one might want to concentrate more on incorporating important information on specific technologies much more into the analysis. One could also focus more on the implementation of different policies.

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Annex 1: Major assumptions within the baseline scenarios

	A1b	*B2*	*A1F*	*B1*
Demand				
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: 12400 US$/ cap)	Strong (2050: 9400 US$/ cap)	Very fast (2050: 12400 US$/ cap)	Fast (2050: 10600 US$/ cap)
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/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
Electricity				
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 for 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
Fuel supply				
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

Annex 2: Relevant statistical data for China

Table 1: Average annual growth rates of economy by industry

Period	Primary	Industry	Tertiary	GDP
1953~1978	2.7	11.4	5.5	6.1
1979~1998	5.0	11.8	10.5	9.7

Table 2: 1953~1995 Coal Consumption by Sector in China (Mt)

Year	Total	Electricity generation	Heating supply	Cooking	Railway	Residential	Others
1953	74.49	6.94		6.27	7.21	29.28	24.79
1962	206.69	30.47		18.84	15.15	72.99	69.24
1976	457.13	79.32		52.48	28.88	93.50	202.95
1980	585.16	126.48		61.78	25.19	106.00	265.71
1985	744.18	164.41	14.62	60.79	15.97	169.83	308.56
1990	1034.27	272.04	29.96	96.31	22.84	189.21	423.91
1994	1285.32	400.53	55.33	139.48	18.73	130.47	540.78
1995	1376.77	444.40	58.87	183.96	13.15	135.30	541.09

Source: 1997 Energy Report of China

Table 3: 1953~1995 Coal consumption mix

Year	Total	Electricity generation	Heating supply	Cooking	Railway	Residential	Others
1953	100	9.32		8.42	9.68	39.31	33.28
1962	100	14.74		9.12	7.33	35.31	33.50
1976	100	17.35		11.48	6.32	20.45	44.40
1980	100	21.61		10.56	4.30	18.11	45.41
1985	100	22.09	1.96	8.17	3.49	22.82	41.46
1990	100	26.30	2.90	9.31	2.21	18.29	40.99
1994	100	31.16	4.30	10.85	1.46	10.15	42.07
1995	100	32.28	4.28	13.36	0.96	9.83	39.30

Source: 1997 Energy Report of China

Table 4: 1970~1996 Major oil products output (Mt)

Year	Crude Oil	Refined oil	Gasoline	Kerosene	Diesel oil	Lubricant	Chemical light oil	Export naphtha	Heavy oil
1970	30.65	27.65	4.59	2.03	6.22	0.78	-	-	8.77
1975	77.06	50.87	7.37	2.90	13.24	1.33	0.45	-	17.71
1980	105.95	75.38	10.79	3.98	18.28	1.97	2.05	0.60	28.85
1985	124.89	84.50	14.38	4.03	19.89	1.43	4.92	1.64	26.41
1990	138.31	107.23	21.57	3.90	26.09	2.09	7.84	0.54	-
1995	149.06	135.01	28.41	4.28	36.84	1.87	11.85	0.01	27.20
1996	157.29	142.32	30.53	5.13	41.09	2.27	13.33	0.01	23.11

Source: 1997 Energy Report of China

Table 5: 1980~1996 Installed capacity and electricity output

Year	Installed capacity (MW)		Electricity output (100GWh)	
	total	Of which: hydropower	Total	Of which: hydropower
1980	65870	20320	3006	582
1985	87050	26420	4107	924
1990	137890	36046	6213	1246
1995	217224	52184	10069	1868
1996	236542	55578	10794	1869

Source: 1997 Energy Report of China

Table 6: 1986~1996 Electricity consumption structure (100 GWh)

Year	Total	Residential living	Industry	Agriculture	Geological exploration	Constructi on	Post, transp. and comm.	Commer cial	Others
1986	4429.1	231.5	3609.5	318.2	2.6	32.4	66.9	41.2	126.8
1990	6120.6	461.4	4819.1	415.3	4.6	45.3	104.8	77.0	193.1
1995	9867.8	1004.6	7387.3	412.2	7.6	108.7	181.7	190.1	575.7
1996	10570.3	1133.0	7830.3	440.7	8.6	115.5	196.1	224.1	621.9

Source: 1997 Energy Report of China

Table 7: 1980~1996 Primary energy output and mix

Year	*Output (Mtce)*	*Share (%)*			
		Coal	Oil	Natural	Hydropower
1980	637.35	69.4	23.8	3.0	3.8
1981	632.27	70.2	22.9	2.7	4.2
1982	667.78	71.3	21.8	2.4	4.5
1983	712.70	71.6	21.3	2.3	4.8
1984	778.55	72.4	21.0	2.1	4.5
1985	855.46	72.8	20.9	2.0	4.3
1986	881.24	72.4	21.2	2.1	4.3
1987	912.66	72.6	21.0	2.0	4.4
1988	958.01	73.1	20.4	2.0	4.5
1989	1016.39	74.1	19.3	2.0	4.6
1990	1039.22	74.2	19.0	2.0	4.8
1991	1048.44	74.1	19.2	2.0	4.7
1992	1072.56	74.3	18.9	2.0	4.8
1993	1110.59	74.0	18.7	2.0	5.3
1994	1187.29	74.6	17.6	2.0	5.8
1995	1290.34	75.3	16.6	1.9	6.2
1996	1315.57	74.8	17.1	1.9	6.2

Source: 1997 Energy Report of China

Table 8: 1980~1996 Primary energy consumption and mix

Year	Consumption (Mtce)	Shares (%)			
		Coal	Oil	Natural gas	Hydropower
1980	602.75	72.2	20.7	3.1	4.0
1981	594.47	72.7	20.0	2.8	4.5
1982	620.67	73.7	18.9	2.5	4.9
1983	660.40	74.2	18.1	2.4	5.3
1984	709.04	75.3	17.4	2.4	4.9
1985	766.82	75.8	17.1	2.2	4.9
1986	808.50	75.8	17.2	2.3	4.7
1987	866.32	76.2	17.0	2.1	4.7
1988	929.97	76.1	17.1	2.1	4.7
1989	969.34	76.0	17.1	2.0	4.9
1990	987.03	76.2	16.6	2.1	5.1
1991	1037.83	76.1	17.1	2.0	4.8
1992	1091.70	75.7	17.5	1.9	4.9
1993	1159.93	74.7	18.2	1.9	5.2
1994	1227.37	75.0	17.4	1.9	5.7
1995	1311.76	74.6	17.5	1.8	6.1
1996	1388.11	75.0	17.5	1.6	5.9

Source: 1997 Energy Report of China

Table 9: 1980~1996 Energy consumption and economic development

Year	Energy consumption growth rate (%)	Electricity consumption growth rate (%)	GDP growth rate (%)	Energy consumption elasticity	Electricity consumption elasticity
1980	2.9	6.6	7.8	0.45	0.85
1981	-1.4	3.0	4.5		0.67
1982	4.4	6.9	8.5	0.52	0.71
1983	6.4	7.3	10.2	0.63	0.72
1984	7.4	7.4	15.2	0.49	0.49
1985	8.1	9.0	13.5	0.60	0.67
1986	5.4	9.5	8.8	0.61	1.08
1987	7.2	10.6	11.6	0.62	0.91
1988	7.3	9.7	11.3	0.65	0.86
1989	4.2	7.3	4.1	1.02	1.78
1990	1.8	6.2	3.8	0.47	1.63
1991	5.1	9.2	9.3	0.55	0.99
1992	5.2	11.5	14.2	0.37	0.81
1993	6.3	11.0	13.5	0.47	0.81
1994	5.8	9.9	12.6	0.46	0.79
1995	6.9	8.2	10.5	0.66	0.78
1996	5.8	6.9	9.6	0.60	0.72

Source: 1997 Energy Report of China

Table 10: 1980~1996 Average per 10000 yuan RMB GDP energy consumption (counted by 1990 constant price)

Year	Total (tce)	Electricity (kWh)
1980	7.89	3935
1985	6.04	3231
1987	5.61	3223
1988	5.42	3177
1989	5.42	3274
1990	5.32	3349
1991	5.13	3351
1992	4.71	3252
1993	4.40	3187
1994	4.16	3147
1995	4.02	3085
1996	3.88	3020
1996	3.88	3020

Note: these data are calculated according to '1997 China Statistical Yearbook' and '1997 Energy Report of China'

Table 11: 1985~1996 Major industrial products energy consumption

Year	Steel (kgce/t)	Electricity (kgce/kW.h)	Synthetic ammonia (middle scale plant) (kgce/t)	Clinker (kgce/t)	Railway locomotive (kgce/10000t.km)
1985	1746	398	2236	201.1	118.7
1988		397	2212	191.2	94.1
1989		397	2193	188.2	88.9
1990	1611	392	2176	185.4	84.1
1991		390	2151	184.0	78.6
1992	1574	385	2155	178.0	
1993	1545	384	2089	177.0	88.1
1994	1519	378	2194	193.8	88.1
1995	1440	376	2194	176.9	88.1
1996	1392	371	2062	173.8	81.4

Source: 1997 Energy Report of China

Annex 3: Literature review on major assumptions within the baseline scenarios

This annex gives an overview of a literature review made for this project.

Blackman and Wu (1999) conducted a research on foreign direct investment (FDI) in China's power sector, this research is described in 'The role of Foreign direct investment in China's power sector'. The researchers involved used data from a survey, official Chinese statistics and other sources. Several conclusions were made. First, if China hopes to significantly boost FDI to meet its capacity expansion and energy efficiency goals, it will have to mitigate the barriers of greatest concern to foreign investors. Those concerns refer to contract enforcement, regulation, and project approval. Given that Chinese contract law is still in its infancy, it is probably not realistic to expect dramatic across-the-board improvements in contract enforcement in the short term. However, the central government might consider a targeted effort to strengthen contract enforcement in the power sector.

Regarding state insurance companies happily, state insurance against default risk presumably creates financial incentives for the central government to enforce power purchase contracts.
With regard to regulation, government officials have mapped out an ambitious strategy for reform. The 1995 Electricity Law, *pricing reforms*, and efforts to separate *ownership* and *control* all represent steps forward. Unfortunately, the pace of regulatory reform is bound to be politically determined.

Perhaps the most promising avenue for improving the climate for FDI in the short term is to codify and streamline the approval process, which by all accounts is unnecessarily time consuming and arbitrary. Presumably, the principal benefit of the arduous central government approval process is that it enables the central government to maintain some degree of control. But the costs of the process are substantial. It clearly creates a bottleneck that limits the total amount of investment. Moreover, it creates incentives to build relatively inefficient small plants. The latter effect is especially perverse since transnational corporations have a comparative advantage in building large-scale plants.

While the conducted research indicates that the approval process has slowed the pace of FDI, it also suggests that it has created strong incentives to enhance energy efficiency and transfer advanced generating technologies. The high costs of negotiating the approval process have even strengthened incentives to develop projects that receive special consideration from regulatory authorities. Ironically, this implies that if the approval process is reformed, these incentives will be weakened. Therefore, efforts to streamline the approval process should be matched by efforts to strengthen incentives to develop desirable projects (Blackman and Wu, 1999).

Historic policies regarding the Energy efficiency in China
In the early 80-ties, the Chinese government made a number of policy decisions to stimulate energy efficiency in a major effort to uncouple energy and economic growth. These decisions, with a good follow-up that resulted in several implementation measures, have been effective. China among others being at the early stage of industrialisation have shown, together with only a few other countries, a consistent and over a long period reduction in the energy

intensity of the GDP. According to Sinton (Sinton et al., 1998), when the energy intensity had remained at he 1977 level, China would have consumed in 1996 about 2.2 times the observed level in 1996. In the following the policy measures and implementation approaches that China used to achieve these results, will be dealt with.

A large share of the government's regulations have been aimed at directly influencing energy use, through applying quota's and standards covering energy intensity, overall energy use and type of energy and energy savings. The quota management system has probably be one of the most rewarding efforts of the government to encourage efficiency improvements. The applied approach greatly has facilitated the governmental control over energy conservation work. The energy quota management system governs the quantity of energy supplied to enterprises, the energy intensity of specific manufacturing processes and deals with monitoring, reporting and evaluation. This energy quota system was the central link of China's energy conservation management system of the 1980s.

Regulations were implemented through government agencies at different levels, with as main purpose to manage energy use. Even financial incentives were put in place to encourage energy efficient behaviour and the development of technologies with improved energy-efficiency. The state, certainly in the beginning of the move regarding the policy, allocated itself budget money to energy efficiency projects, inclusive in the installation of efficient equipment at industrial enterprises and for the support of research and development (Sinton et al., 2000). However support for R&D is not a very impressive activity, but even though has been one of the most important aspects of China's venture to promote efficiency. One of the very distinct features of China's overall efforts to reducing their energy-intensity of the GDP, was the establishment of efficiency technical services and training centres apparently throughout the ministry systems and in major cities. These centres provided assistance in specific technical matters, and took responsibility for public education campaigns.

An overview of China's national energy conservation policies is given in the table.

Table 1: Overview of China's national energy conservation policies

Strategy	Major Policy measures
Energy efficiency and energy conservation management	Control unit energy consumption (energy intensity) and energy supply through quotas. Place controls on oil use, substitute coal for oil. Disseminate energy-efficient technologies and products. Retire energy-intensive mechanical and electrical devices restrict energy-wasting production practices. Create energy efficiency standards for buildings and residential appliances. Monitor enterprise energy conservation.
Financial investments	Set low interest rates for energy-conservation project loans. Tax breaks for energy-efficient products. Provide monetary energy conservation awards to enterprises
Direct investment and research, development and demonstration	Establishing national agency for funding efficiency investments: the China Energy Conservation Investment Corporation. Develop national strategic science and technology plan (funded projects). Carry out demonstration and dissemination projects (low interest loans, tax breaks and other financial assistance). Encourage enterprise self-development (funded through 1-3% of sales income).
Information and technology service	Establish national resources conservation and comprehensive utilisation information network and database. Establish national, local, and sectoral energy conservation technology service centres.

Strategy	Major Policy measures
Propaganda, education and training	Establish and maintain an energy statistical reporting system, including capabilities and methods for energy supply and demand forecasting. Each October hold activities for an Energy Conservation Awareness week. Include energy conservation in primary and middle school curricula. Establish national, local and sectoral energy conservation training centres.

Source: (Sinton et al., 1998)

Challenges regarding the policies enhancing Energy efficiency in China in the future
China's economic system is in transition from a centrally planned economy to a more market-based economy. Thus in the present state of transition, it shows both features of centrally planned command and control economy on the one hand it consists of elements of a regulated, market based system on the other hand. It is posed that this situation causes incompatibility for organisations and practices. The institutions and rules that will have to govern the coming market economy do not yet function as intended. It is thought that the government will have to maintain their role in improving end-use efficiency, however it need be done in a different manner. The question is, what the most appropriate way is to govern this process in the new and changing environment. According to Sinton et al., (1998) it is showed that their is at least a serious demand from enterprises from varying scale, directed to the government for the application of policies and regulations to steer energy conservation work.

The 'Command and control' types of measures are believed to be unsuitable to the new and fast developing environment. Some measures, will be mentioned in the text to follow. Energy pricing is one direction of thinking to rationalise energy use, via for example improvement of the end-use efficiency in China. It also referred to as 'getting the prices right'. It is mainly intended to get prices at the level where they reflect their long-run marginal costs of supply. In addition it is preferred that the major externalities, like environmental damages are included. It is admitted that in market based economies, like China is developing to, the price signals are crucial in shaping patterns of energy use. In 1993 already, the government carried out a number of reforms affecting prices of energy like in finance, taxation, investment, foreign exchange and so forth, thus stimulating energy price system development. After years of extensive debate the goal of energy prices to be set mainly by the market received general approval. Overall, the liberalisation of coal prices in contrast with oil and gas prices, represents the most significant breakthrough in energy price reform (Sinton et al., 1998). The reform of coal prices is suggested to be reasonable complete, however one might doubt, to what extent external costs are internalised. But other factors beyond the prices, like non-market barriers to efficiency investment, are expected to be of more importance.

Financial incentives like tax brakes and interest subsidies are important ways to encourage investment in market economies. Compared to other types of projects like production capacity expansion, end-users typically require for projects enhancing energy efficiency, a better performance represented in shorter pay back periods. Some local administrations still provide financial incentives, but national incentive programs were lacking, what causes a major gap in the state's stock of measures to stimulate efficiency (Sinton et al., 1998).

The structures and institutions created under the planing system for promoting efficiency are now in an uncertain situation because of the transition. There is now a serious treat to the energy management apparatus, the share of the society that is controlled directly by the government itself is in decline. And the quite valuable energy conservation service centres have lost much of their funding. Now they have to survive under the new and developing regime. It is a dangerous period because when these institutions would disappear completely it might be very difficult to bring back. Preserving existing infrastructure (as far relevant though) by aiding and facilitating their transformation into an institutional setting that is able to deal with the new establishing market economy is supposed to be a far wiser course, compared to the re-establishment of a similar set of institutions for the near future.

The draft energy conservation Law was passed in 1997. This Law represents a major step in institutionalising programs and incentives to promote efficiency. Actions will strengthen both existing institutions and create new ones that are appropriate to a market-oriented system. The Law draws the broad figure, where further detail has and will be brought in the near future by several commissions.

Sinton et al. (1998) lists practices which to them are likely to occur, these consists of:

- Key energy-using enterprises would hire energy managers who have passed a national examination.
- Key energy-using enterprises would have periodic energy audits performed by qualified independent consultants.
- Financial incentives would be reinstated to encourage energy-efficiency research, development, demonstration and investment projects, with eligibility determined by standardised criteria.
- Ceilings on manufacturing energy intensity would be placed on various products, where current practices will be turned into law.
- Mandatory energy-efficiency standards would be developed for certain categories of equipment and a certification initiated.
- Feasibility studies for new fixed asset investment projects would include a section on energy conservation.

China faces serious challenges to ensure that energy improvements will continue. It is believed by Sinton et al., that the data gathering system at both firm and the national levels must be redesigned and strengthened as quickly as possible. They see as one of the most important research task to see how one could build, staff and fund a reliable statistical apparatus. Furthermore they suggest that China should continue its funding support for investment aiming at improvement of efficiency. Regarding eligibility of projects, a valid set of criteria needs to be selected. Establishment of mechanisms that leverage state and international funding by attracting private capital is issued as a central task.

Besides efficiency standards have proven to be a very effective tool in improving the energy performance of equipment in other countries. While China has some standards, the implementation potential is said to be limited. Facilities for design and testing of facilities are inadequate to handle the volume of work that would be required to apply standards to more than only a few product categories. In the appearing transitional environment the problem of assuring the continuity of the organisational basis for efficiency promotion (particularly the energy conservation service), might probably need to get the most attention. The personnel of these centres are, as well as the ones in the energy management bureaus and enterprise energy managers are an irreplaceable resource. Conversion of energy conservation centres into energy service companies is one important way to proceed. For the future it is suggested that, while the economy and the energy system is in a tremendous transition, there is looking to past efforts a critical resource. This is supposed to be corps of dedicated leaders and professionals with a deep understanding of the need for efficiency and the skills necessary to achieve it.

The relevance of community energy management

Chinese cities are experiencing serious environmental effects from fossil fuel-based energy consumption for mainly residential and, increasingly, urban transportation uses. Community energy management (CEM) is believed to be a sustainable energy strategy which looks at how purposely shaping the built environment and designing urban services in consideration of energy production, distribution and use could affect both the long-term demand for energy and the type of energy supplied. This energy policy perspective may be particularly relevant to China, since it is facing rapid urbanization (Sadownik et al., 2001). Researchers from Simon Fraser University studied what CEM is in a Chinese context and suggests CEM strategies that would be appropriate in directing urban development towards a more sustainable energy path. A model is used to evaluate aggregate energy-related emissions in the year 2015 in China. The model focuses on how energy demand, residential energy technology penetration and transportation mode choices are affected by factors in neighborhood development. Results from their exercise suggest that China can achieve urban residential and transportation emissions reductions of approximately 14% for CO_2, 10% for SO_2, 40% for NO_x and 14% for particulate emissions in 2015 by adopting certain aspects of CEM.

CEM strategies that may be appropriate in China include:

- Encouraging a greater diversity of energy sources and encouraging renewable technology appropriate to the end use task.
- Replacing decentralized and uncontrolled coal combustion for individual apartment blocks and dwellings with community facilities with environmental controls.
- Developing co-generation and district energy further, emphasizing larger-scale, integrated systems. District energy/co-generation could be made more economical by also supplying hot water to public bath houses and private dwellings as that market develops, and by providing both district cooling and heating.
- Encouraging gaseous fuels.
- Encouraging land-use development that will make district energy most economical.
- Facilitating the continuing use of bicycle transportation.
- Improving the quality of public transportation in conjunction with land-use planning.
- Encouraging greater mixed land use and density in suburban developments. The dispersal of activity centers and increase in local neighborhood services need to follow outward extensions of the city.
- Encouraging the interaction of industrial energy provision with community energy through waste heat utilization.
- Maintaining mixed land use in central areas (Sadownik et al., 2001).

Looking to the implementation of CEM, Land use planning in China needs to be integrative and holistic in order to influence urban development including urban growth, industrial, commercial and residential siting and infrastructure development. Referring to energy planning part of CEM optional policy measures include:

- Encouraging commercial banks to offer preferential interest rates for energy efficient and alternative technology investment.
- Reinstituting the tax exemption for delivery heat.

Adjusting the tax treatment of energy equipment expenditures to recognize that most renewable resource have no fuel costs to be deducted from revenues for tax purposes. Using financial incentives to encourage technical upgrade investments as an effective way to solve capital constraint problems. As part of the Transportation management, the motorized transportation needs to be actively managed through a holistic planning process which fully considers all alternatives including demand management. China currently has a window of opportunity to establish effective transportation policies before motorization is too far advanced.

Finally China is well suited to adopt the CEM perspective, in particular while it is now in a position being able to shape market forces before practices become entrenched. To adopt CEM, some key challenges are believed to overcome. Economic opportunities are short term and immediate and are difficult to streamline with sustainability concerns. An important aspect will be costs of pursuing CEM strategies and of course of alternative strategies to reduce emissions. The authors pose that costs are likely to be relatively low per ton CO_2, SO_2, NO_x or particulates reduced. It is believed to have additional financial benefits in providing infrastructure en energy and other non-cost benefits such as a relatively greater employment and reduced loss of agricultural land to urban sprawl (Sadownik et al., 2001).

The role of monitoring and enforcement

Monitoring and enforcement issues have been limited studied, particularly when one issues the empirical aspects. A research carried out by Dasgupta et al., (2001) tried to get better understanding of the impact of regulator's monitoring and enforcement activities on the behaviour of industrial polluters. The way the researchers looked at it, is that inspections and pollution charges jointly determine the expected penalty faced by a firm that fails to comply with the regulatory standards. The results demonstrate that at the plant level, the variation in inspections is a better determinant of the firms' environmental performance than is the variation in pollution levies. This result may provide some additional insight in how to proceed to support the steps to be taken to improve China's future quality of environment. However the results doesn't tell anything about the effectiveness in allocating part of the resources to monitoring activities. However, given the high level of pollution observed in dense populated and or industrialized cities and given the impact that these may have on health and productivity deterioration it is, according to these researchers that inspections can increase social welfare in certain areas in China.

The researchers also postulate that the results they actually found, may suggest that informed citizens can have an important impact on pollution (via inspections). Referring to similar research findings, it is has been analyzed what the determinants of citizens' complaints are in China. And it was found that these complaints were an increasing function of the levels of income and education. This would suggest a greater role for the regulator to embark on information and education policies. Additional research in this area will be needed to get a better understanding what the precise lessons are which are to be learned (Dasgupta et al., 2001).

Energy Demand

According to Sinton et al. (2000) in recent years, China's energy output has dropped by 17%, and the primary energy use has fallen by 4%. This is mainly due to the shrinking output from coal mines and decline of direct energy use. This impressive change in levels of energy has occurred while at the same time the economy still grows significantly, however at a lower rate.

China is the world's second-largest emitter of greenhouse gases. It is therefore relevant what is behind these figures and whether it implies a persistent change in the trend of energy-use.

A number of drivers explain the phenomenon. Sinton et al. (2000) mentions, the shutdown of factories in both the state-owned and non-state segments of the economy. This process is initiated by the central government, which required a reduction in the output of the coal mines, as part of an package of measures to reform the financially troubled state-mines. Over 25000 small coal mines and 40 state-owned mines have been closed. Also unsafe and in several occasions low cost coalmines were prescribed to close. The establishment of a more balanced coal market with less overproduction and reduction of coal stocks is one of the objectives of these reforms. However, the precise interpretation of the remaining stocks is somewhat uncertain.

Furthermore, Sinton mentions structural changes in industry and the broader economic system reforms. The structural change like for example an increase in the share of services and a decline in the share of industry is not thought to be a valid explanation according to Sinton et al (2000). Heavy industry still continues its growth. However, within the different sectors, significant changes are observed, represented by a change in the product-mix, inclusive production of high-value-added products.

Another driver is the improvement of coal quality, improvements in end-use efficiency, and greater use of gas and electricity in households. The development of the so-called buyers market is enhancing the coal-quality improvement. Sinton, concludes that about 40% of the decrease in energy consumption after 1996, might be attributed to the higher quality coal. The increasing energy content of the coal of course reduces the carbon dioxide emissions even more.

Furthermore there exist environmental and energy-efficiency policies which cause a long-term reduction in the growth of energy use, and therefore greenhouse gas emissions. However the latter on might already have its impact for a period longer than the last 5 five years.

To continue on the track of improving the energy-intensity, one might discover that many of the easily available efficiency gains already are realised (Garbaccio et al., 1999). In viewing the economies structure one could say that the share of the industry is quite stable. The further development of the service sector may reduce the energy intensity in the future, but this effect can be compensated by an increase in the growth of motor vehicle use.

It is hoped that prices in the future more reflect the overall costs, thus incorporating externalities. This can be done via application of additional environmental taxes, additional to the already scarce ones in operation. In turn the higher prices may continue to stimulate energy saving technological change (Garbaccio et al., 1999).

Energy Supply

Dorian et al. (1999) have elaborated on the current and future status of the energy industry of central Asia, and have assessed opportunities for regional-wide co-operation in development, transportation and trade. In this research they have been focused on central Asia with Uzbekistan, Kazakhstan, the Kyrgyz Republic and Xinjiang, of the People's Republic of China. Xinjiang PRC borders on to the other three former soviet republics mentioned. Xinjiang PRC, together with Kazakstan are the major coal producers in central Asia. Xinjiang PRC has the strength that it possesses large amonts of high-quality coal resources, with resources of approximately 3.03 billion metric tons (bmt), what is about 2% of the country's total reserves. Coal is abundant in Xinjiang PRC, these reserves are concentrated in the North

Tian Shan mountains area. In 1996 for example 60-70 percent of Xinjiang PRC's electric power generation was fuelled by coal. Transportation is the key problem for coal in trade in region, given that great distances separate markets from reserves. In Xinjiang PRC transportation capacity constrains the use of coal, with making output largely dependent on very local demand. The completion of a rail line from Korla, in central Xinjiang PRC, to Kashgar, in the south will provide the capacity to ship coal from the northern coal fields to the newly industrialising south.

Electricity shortages are a major problem in the whole region, in particular Kazakstan and Xinjiang PRC. Because of fast industrial expansion, the electricity demand is growing faster than supply.

In Xinjiang PRC, wind and solar resources are abundant. Local government officials hope to augment local power plant capacity by attracting investment and joint-venture partners to develop wind and solar further beyond what is already put in place.

Diversification of energy sources and markets is a sound strategy the countries of Central Asia are beginning to consider. Central Asia, with Xinjiang PRC is at a stage where the adoption of appropriate strategies can reap tremendous future benefits. The PRC, depends heavily on the Middle East for imported oil and oil products, making the country vulnerable to erratic price swings or political disruption in Middle Eastern oil supplies. The PRC could develop a viable alternative source of supply by importing Kazakstan crude oil into Xinjiang PRC. Xinjiang PRC and China as a whole should also consider the widening in diversifying their markets for the longer term. Regional energy co-operation from Xinjiang PRC with its neighbouring countries in central Asia can benefit these countries in three significan ways:

- Supplementing local energy supplies;
- Providing more economic and efficient supplies of energy to specific areas even if such resources are available locally and;
- Transportation energy resources to markets outside of the region.

In addition co-operation is welcome in order to let Xinjiang PRC meet its projected deficits and the reduced estimate in the Tarim basin might be another reason.

Finally, for Xinjiang PRC it is believed that the most important energy objective is to obtain reliable long-term supplies to sustain its economic growth. The major impediment to regional co-operation and achieving these objectives would be the absence of infrastructure for transporting energy. Xinjiang PRC lacks the infrastructure to import the energy resources it requires. Overcoming these infrastructure constrants is an important priority for the agencies of the Xinjiang PRC, the government of PRC and for other Central Asian countries as well (Dorian et al., 1999).

GHG-emissions from end-use conversion devices at the household level

Emissions from household stoves, especially those using solid fuels, can contribute significantly to greenhouse gas (GHG) emissions and impacts (Zhang et al., 2000). The researchers have described their research in the article of Zhang et al. (2000). The researchers have measured the emissions from 56 fuel/stove combinations in India and China, with a large fraction of them in use-world-wide. An evaluation was made of direct and indirect GHGs and other airborne pollutants. The results from the analyses show that total emissions per unit delivered energy were substantially greater from burning the solid fuels than from burning the liquid or gaseous fuels, due to lower thermal and combustion efficiencies for solid-fuel/stove combinations. When one relate the findings to the energy content of the fuels, it is clear the solid fuels had substantially lower energy content than the liquid and gaseous fuels. In fact the ranking follows the order of the quality of the fuels. The higher the quality the lower the emissions and the higher the efficiency.

The fuel types selected represent those being used commonly in rural households, e.g. crop residue, kerosene and coal and those being used in urban households (e.g. gaseous fuels, coal and kerosene).

As an indicator of the cleanliness of the combustion from the fuel/stove combinations the sum of emission ratios of all carbon-containing species other than CO_2 in the flue gas is used. This indicator represents the emission ratio for total product of incomplete combustion. Since the ideal combustion would convert all carbon in the fuel burnt to CO_2 solely, the earlier mentioned sum of emission ratios of all carbon-containing species different from CO_2, is inversely proportional to the nominal combustion efficiency (Zhang et al., 1999). The results from the research show that the coal gas and natural gas had the highest combustion efficiencies, followed by kerosene and LPG, then followed by various coals and fuel wood, and then by crop residues and brush wood. The results show a very wide range for the sum of emission ratios of carbon containing species different from CO_2, namely in the order of magnitude of 4.

It is estimated that 20-50% of global greenhouse gas (GHG) emission is due to biomass combustion, either for land clearing (large-scale) purposes or to benefit household requirements (small scale). There exist clear differences between emissions from these small scale combustion compared to the open large scale burning.

Surprisingly, it is often assumed that biomass harvested from renewable sources, do not contribute to global warming, because the related carbon is entirely recycled through photosynthesis in the growing process. However, biomass harvested from renewables, cause, next to CO_2, the release of the numerous other gases mentioned earlier, which is the product of incomplete combustion. The released gases contribute to global warming because of their higher radiative forcing than CO_2 and possibly even more because their indirect greenhouse effects. Thus, biomass fuels burned have, due to the contribution of non-CO_2 GHGs, the potential to produce net global warming, even when grown in a renewable manner (Zhang et al., 2000).

In addition and not to neglect, the researchers have found that for a given biomass fuel type, increasing overall stove efficiency tends to increase emissions of products of incomplete combustion, what might be opposite as what one expect et first hand. This is due to the fact that overall stove efficiency is the product of combustion efficiency and heat transfer efficiency. The overall efficiency might be increased due to improved heat transfer efficiency via for example better insulation, the latter may as a consequence reduce the combustion efficiency. Therefor the authors of the article opt for an integrated assessment of GHG emissions, thermal efficiency and even health impacts. This, in order to provide a more balanced, fair and complete evaluation of combustion devices in general on these three aspects (Zhang et al., 2000).

Mitigation Scenarios - IIASA scenarios

In this paragraph we refer tot the regional distribution applied by IIASA and presented in Nakicenovic et al. (1998). China is in this regional constitution part of the region ‘Centrally

Planned Asia and China (CPA)'[11]. In terms of population, economy and energy use, China dominates the region. China accounts for 91% of the region's population, 78% of the GDP, and 92% of the commercial energy consumption (Nakicenovic et al., 1998). The energy use in the CPA region is still rather inefficient despite the large past reductions in energy intensity. For 1990, the figures for another region defined by (Nakicenovic et al., 1998), namely the pacific OECD region (PAO) with Japan, Australia and New Zealand, are less than 0.2 kgoe/US(1990)$ for primary energy intensity, that means more than a factor 10 lower than the CPA-region. Therefor the potential for improvements is said to be low (Nakicenovic et al., 1998). The main reason for the high energy intensities in the CPA-region is the current structure of the energy system. The dominance of solid energy forms in both primary energy mix and at the final energy consumption implies relatively low energy conversion and end-use efficiencies. The commercial energy grids (like electricity and gas) do not reach the estimated 350 million people in the region, and mainly in China, who live in poverty. Only a very small part of all final energy is delivered by grids in the form of electricity and gas or as liquids (mainly oil products).

In the six scenarios from IIASA (Nakicenovic et al., 1998, p213) a common feature is the future shift from non-commercial energy and rather inefficient energy use towards higher-quality and efficient fuels. They point to liquid fuels and the grid-dependent forms of energy. This transition is believed to serious efficiency improvements and has impressive potential to reduce indoor and urban air pollution. According to Nakicenovic, the per capita final energy consumption exceeds 1.6 toe by 2050 and touches 2 toe by 2100 in the high-growth case. These are levels of 1990 for Japan and Europe. The share of solids is believed to decrease from 77% in 1990 to between 33 and 55% of all final energy by 2050. Therefor, it will result in energy intensities decline. Between 1990 and 2020 the primary energy intensity decline will at average be between 2.2 and 4.2% per year. After completing the transition towards commercial energy, after 2020 it is believed that the improvements rates will decline, ranging from an annual 2.2 to 2.8%. Nakicenovic et al. poses that all coal-based and biomass energy reaches consumers in the form of electricity, liquids or gaseous fuels. Besides, the higher growth rate of the economy, the higher the expected levels of investment and the quicker the old capital goods and equipment is replaced by new, less energy-intensive alternatives. Which itself drives the energy-intensity even quicker in the preferred direction.

From the technological viewpoint it could be possible while China now catches up technologically, it might discover all kind of opportunities to leapfrog development stages. Development stages, that were experienced to be essential in the development paths originally taken by the present technologically forefront. Therefor it is imaginable that technology may develop more quickly in China than it did in other countries or regions, when they were at the same stage of development. As part of these experiences it might be possible to leapfrog old infrastructures, and pave the way for new infrastructures. In general, it is clear the diffusion of technology will take time. In particular the network-like infrastructures have a serious path-dependent nature, therefor choices to be made right now or in the near future, might have long-lasting consequences.

In general more efficient and higher quality energy carriers will be the line, but quite different ways can be observed across scenarios of IIASA. Coal is assumed to continue playing a serious role in different scenarios, at least to 2020. A major change to occur around 2020

[11] The CPA region includes Cambodia, China, Korea Democratic People's Republic (DPR), Lao People's Democratic Republic (PDR), Mongolia and Vietnam Nakicenovic et al. (1998). Global Energy Perspectives. Cambridge, Cambridge University press..

carries a danger of causing stranded costs for the infrastructure in place, like for example at present in China 40% of all railway operations are dedicated to transport of coal, this may even grow seriously till 2020. While later on but around 2020 this growing infrastructure need to be extended by the new infrastructures to transport natural gas and probably energy from renewables and thus require investments again. In addition a delay in investment in the grid-based infrastructures might cause lower progress in learning.

Nakicenovic et al. poses that probably the major near term political, institutional, infrastructural, technological and financial challenges the region and thus China will face in the energy sector will arise from the need to expand pipeline capacity and connections. Such energy networks could further in the future, facilitate the development of the vast Caspian and Siberian energy resources. Such energy-network might be become intertwined with the rest of Asia with serious strategic benefits (Nakicenovic et al., 1998).

Considering other environmental issues, the poor urban air quality resulting from particulates and sulphur emissions is relevant. These emissions have direct health effects and longer-term acidification impacts that next seriously will harm agricultural production and ecosystems, thus affecting a big share of China's population. A combined approach to limit both sulphur and CO_2 emissions is preferable, and could be enhanced via a focus on steered technological progress and use of energy resources other than coal.

Efficiency of thermal power plants
According to Zhang et al. (2001) the rapid capacity building, the technologies and the energy efficiency used in electricity generation have undergone important changes. The heat rate is used as the measure of the changes. Heat rate can be defined as grams of standard coal equivalent (gsce) consumed per kWh electricity generated (gross heat rate) or supplied to the grid (net heat rate). It is a widely used indicator of the energy efficiency of power generation. The lower the heat rate, the more efficient is the plant.

The heat rate of a power plant is determined by two sets of factors. First, the plant's maximum energy efficiency is set by the technical design and embodied in the specific vintage of capital equipment. This level of efficiency is determined at the time a decision is made to adopt a specific technology and scale of capital equipment. These decisions determine the upper bound of the plant's energy efficiency for the lifetime of the capital equipment. It is the *ex-ante* energy efficiency. Second, the plant's real achieved efficiency is usually lower than the ex-ante efficiency. (The heat rate is higher.) There are a number of factors associated with the plant's ownership, management, operation practice, equipment wear and tear, quality of coal, etc. that can cause the plant's energy efficiency performance to fall below its maximum designed efficiency.

For China only few studies exist which look at the empirical evidence and distribution among the different factors on the energy performance of for example coals-fired power plants. Observations suggest that both inefficiencies exist in China. But it is found that the *ex ante* efficiency change may be the dominant factor behind the energy efficiency pattern shifts observed over China, particularly pointing to the cases where the installed capacity has been built recently (Zhang et al., 2001).

However a big potential for improvement of energy efficiency is not utilized, even the rapid growth in several places and provinces of China has not led that only the most efficient coal to electricity conversion technologies are implemented. Even the most inefficient technologies are used in new plants. What causes that still a serious part of the coal-fired electricity generation can be characterized by poor energy efficiency performance. It implies that still huge challenges exist for additional requirements in the rapid market and institutional developments underway in China.

Annex 4: Categorisation of policy instruments

In this Section we will treat in brief different categories of instruments and some aspects of the their functioning. There is extensive literature, both theoretical and empirical, to identify and discuss policy instruments related to environmental issues like for example: Perman et al., 1996; Tietenberg, 1994; WRR, 1992; Baumol and Oates, 1988.

In this report we distinguish a limited number of main clusters of instruments:

- Economic instruments, influencing the decisions made on the basis of relative costs and prices such as taxes, subsidies and loans;
- Regulation, including instruments such as appliance standards, building standards, environmental laws and the like;
- Technology support, in the form of Research, Development and Demonstration project.
- Social instruments, including information campaigns, education and the like which attempt to disseminate adequate knowledge and increase awareness.
- Institutional advancement
- Arrangements between governments and organisations

The World Bank distinguishes four categories: 1. Using markets, 2. Creating markets, 3. Regulating, 4. Engaging the public. All the four mentioned, can be applied at two levels, for either resource management or alternatively for pollution control. The Scientific Council (WRR, 1992) distinguished also four classes which are 1. direct regulation, 2. financial instruments, 3. Civil law, 4. Social rules.

Economic instruments
Economic incentives are characterised by the methods used to reach the predetermined objectives. For economic instruments, the government is mostly the initiator. Economic instruments are in many ways combined with other instruments like for example technological change by subsidising application of new technologies. Economic instruments use economic incentives to achieve environmental or other goals. The basis of the system is formed by the providence of an sufficient financial incentive to an actor (or agent) to bring individual objectives in line with objectives of the society.

The World Bank refers to this type of instruments by naming it creating or either using markets. What is important in this respect is the establishment of property rights for scarce resources, like clean energy or clean air. Privatisation is by the World Bank also believed to be useful in moving many aspects of environmental management out of the state sector into more commercial operations. Tradable emission permits as an example recognises the value of scarce resources by translating it in economic terms. This recognition might enhance the efficient use of the scarce public resources. The initial allocation requires severe attention to prevent for unwanted outcomes. Several other examples of straightforward economic instruments are apparent.

Regulation
In regulation the objectives are achieved on a mandatory basis and the position of the government is central in regulation. The bans, standards, permits and so forth, are often

preferred because of their certainty of outcome. The other instruments considered also require regulation in many occasions, although that is not their main characteristic.

'Public engagement' functions just the opposite, compared with regulation, although the initiating role of the government is often obvious. Objectives are achieved on a voluntary basis. 'Public engagement' acts directly on agents anywhere in the energy system. Information disclosure and public participation are the general objectives. The group of communication instruments that is used to reach these objectives is diverse and contains many options to achieve 'win-win' situations (WRR, 1992, p. 98-106). In several countries one can find special programmes for extension and education in which a miscellaneous set of activities might be distinguished.
Extension in general can be operational as an independent instrument or as a supporter of other instruments. The ultimate effect is a voluntary change in people's behaviour.
The general idea is to get people motivated to adopt the changes, which are wanted in the system. The use of this type of instruments in combination with other instrument types for instance economical incentives, can improve be very each others effectiveness.

Institutional advancement
Institutional advancement instruments are instruments, which act indirectly on agents within the society. Institutions (together with available technologies) set the conditions for individual decision making. Those conditions might change over time and governments or other public and even private actors might contribute to such changes. 'Institutional advancement', however, acts much more indirectly because the institutional organisation will be changed, with the intention to change people's behaviour that follows from that. The government agrees with an organisation to reach certain objectives. The role of the government is limited to evaluate whether the predetermined objectives are nested in the right way and to administrate the effectuation of the agreement.

Arrangements
Arrangements or in other words covenants are in fact contracts between governments on the one hand and organisations on the other hand. Their main intention is to find an agreement on a number of targets that are clearly formulated. The main reason why organisations might be interested to agree on such targets is the threat of promised other policy instruments, which might affect these organisations even more severe.

As indicated, each group of instruments has special characteristics. In practice, these several different characteristics of a policy instrument can play a role in the overall reduction of energy use or either carbon emission reduction.

Table 1. Overview of potential policy instruments

Policy Instrument	Type	Where to operate [1)]	National (N) Provincial (P) Regional (R)	Remarks
Regulation				
Restricted use of low quality coal	Regulation	Coal industry	N/	Authorisation, definition of quality.
Eliminate out-of date equipment	Regulation	Industry, households, other	R	
Quota management of energy use	Regulation / Economic instrument	All	N	Can be coupled with either premiums and charges
recording of sales	Regulation / arrangements	Mining industry	N	statistics of total sales per mine
monitoring of CO_2 emissions at industries	Regulation / awareness	Industry	R	Ease the environmental burden via information providence
Public engagement				
training and education of constructors / installers	Information / awareness	Stakeholders /construction-org	N/R	requirements on training and equipment
Energy efficiency labelling	Information & awareness / Institutional adv.	market / consumers / industry	N/P/R	Label for renewable, low carbon containing or without coal produced electricity for example or energy efficient appliance labelling
Institutional advancement				
Programme on energy saving management	Institutional advancement / inform. & awareness	other / industry / stakeholder org. (industr.), market / consumers / other	/R	

Policy Instrument	Type	Where to operate [1)]	National (N) Provincial (P) Regional (R)	Remarks
Eliminate out-of date processes in industry	Institutional advancement	Industry, construction	R	
programme on LCA & cascade use in industry (environmental subsidy programme)	Institutional advancement / Economic Instrument/ inform, awareness	Industry / industry organisations / other	N/P/R	
Stop price support for coal & coal products	Institutional advancement	Industry		
Deregulate the transport price	Institutional advancement / economic instrument	All ?	N/	Going into direction of use of transport means are priced (include external effects where acceptable)
Technological change				
Reduce of iron and steel ratio	Technological change / economic Instrument	Industry	N/ /R	
R&DD of new energy saving technology	Technological change	Research centres Households, all	N	Fundamental R&D at national level. Demonstration on regional level
improvements in appliances for cooking / heating	Technological change	Households, construction industry	N/P/R	
Measures to extract CO_2 from exhaust gases on purpose	Technological change		/P	

Policy Instrument	Type	Where to operate [1)]	National (N) Provincial (P) Regional (R)	Remarks
Adjustment of transport infrastructure	Technological change / Institutional advancement	Stakeholder organisations (for transport) and provincial governments	N/P	Task for National and provincial governments
Arrangements between governments and organisations				
covenants or contracts	arrangements	industry / retail / other	N/R	Implement CO_2 emission reduction plan (as substitute for levy for example)
Economic incentives				
VAT on energy	Economic instrument	All	N	Uniform tax eventually coupled to C-content
premiums to promote large scale equipment	Economic instrument	Industry / market / other	N/R	
marketable rights / marketable emission per-mits	Economic instrument	All or Industry / Energy retail / other	N	Or complete society or just industry (C-intensive first)
stimulation of any other (technical) measure by financial compensation	Economic instrument /technological change	All	F/P/R	
private law instruments				
Energy reduced use clause in contracts between house owners and users	Private law / arrangements	House owners / Households	R	private law most probably need adjustment

References: Oskam et al., 1998; Worldbank, 2001; Xueyi, et al., 2001a; Xueyi, et al., 2001b; WRR, 1992

[1] Possibilities for where to operate:

1. Industry (i.e. Iron & Steel Industry or electricity producers or Building & construction industry);
2. Energy retailers (i.e. coal or oil sales);
3. Stakeholder organisations (i.e. for department stores or for farm-org.);
4. Tenants, inclusive contractors (i.e. in housing sector);
5. Market organisation (i.e. ..);
6. Consumers (i.e. consumer stakeholder organisations);
7. Other private or public organisations.

Table 2: overview from other studies regarding expected effectiveness of energy related technical measures to mitigate CO_2 emissions in the future

Policy instrument	Technical measure	Effectiveness [1)]	View year [2)]	Remarks	Reference / study
Community Energy Management (CEM), representing a number of possible measures	Consider energy prod., cons. & use as an issue in shaping the built environment & in designing urban services	14 % reduction in CO_2 emission	2015	In fact in CEM numerous strategies can be included, like more divers energy sources, community facilities, develop co-generation, encourage gaseous fuels, facilitate bicycle transport, and so forth	(Sadownik et al., 2001)
Monitoring and enforcement (optionally including penalties or charges)	Monitoring & inspection activities at industrial sites	n.q. from other studies numbers of 20% till 28% go round, however this is for other emissions types	n.r.	Limited studied, therefor no clear estimate	(Dasgupta et al., 2001)
Where non-existent, development of a so-called buyers market	Application of higher quality coal	Some percent points	In five years	This clearly has an upper limit, the coal quality cannot be improved unlimited. Also replacement by gas has its drawbacks	(Sinton et al., 2000)
Facilitate / promote regional co-operation in Asia, like with former Soviet Republics	Co-operation needs in some places be facilitated by improved infrastructural means like railroads. Cross-border infrastructure facilities can ease the benefits from each other.	n.q. The better coal quality is one of the drivers		Economic strengthening is the major priority, but it can thus in several ways enhance environmental performance as well. The load factor for electricity production can significantly improve Also use of renewables may be enhanced because of abundant sources in Xinjiang Economic strengthening might help to raise fund for further energy efficiency improvement	(Dorian et al., 1999)
Integrated assessment of GHG emissions with thermal efficiency of end-use conversion devices	Improve combustion efficiencies (in order to avoid generation of other GHGs (apart from CO_2) with high radiative forcing and eventually high indirect greenhouse effect	n.q. Can be enormous, when generation of other GHGs can be avoided	2000 – 2001	Enormous variation in empirical study is found in the ratio of other carbon containing species with CO_2 as a result from incomplete combustion from household stoves. Moreover improvement of overall stove efficiency, tends to increase incomplete combustion.	(Zhang et al., 1999)
Facilitate development of	Shift from traditional fuels to	n.q. separately.	1990-	Opportunities for leapfrog development	(Nakicenovic

Policy instrument	Technical measure	Effectiveness [1)]	View year [2)]	Remarks	Reference / study
grid-based infrastructure	modern commercial, grid based (non-solid) energy forms/fuels, to get better energy conversion efficiencies	Generally a decline in energy-intensity of 2.2–2.4% is proposed	2020	stages may very well be imaginable. Variations amongst the scenarios exist. The shift will significantly benefit the indoor and urban air quality.	et al., 1998)
Evaluate the design of new power plants and restrict/ban inferior, old-fashioned, in-efficient technologies to be used anymore.	Ex-ante energy-efficiency improvement. By installing superior technology, instead of what is still observed, namely practices of new installation of the most inefficient technologies in new constructed power plants.	n.q., 25% / kWh for electricity at maximum effect can be significant Believed, that big potential of ex-ante energy-efficiency is still not utilised	2010 Several decades ..	Because of long-lasting lifetime of power plants, energy characteristic of applied technology has long-lasting effect (so-called ex-ante E-efficiency). Therefor taking action immediately will have long lasting gains. Success will heavily rely on success of institutional reform	(Zhang et al., 2001)
Combination of: - Population control - Energy conservation - Develop renewable E. - Enhance Sinks	Various technical measures are considered: - improve energy efficiency and conservation - develop new & renewable energy and improving energy structure - greater efforts for afforestation - Capture and underground storage of CO_2, i.e. combined with enhanced oil recovery - Recovery of coal –bed methane - methane utilisation in technology in the countryside (incl. Integration)	- n.q. (population low till 2040 stabilise after 2040 - conservation rate will be 5% per year - n.q. intensified nations efforts to develop renewables - n.q. enhance C sinks, like in forest	- before and after 2040 - - -		(Huaqing 1999)
Promotion and facilitation of the introduction of attractive IGCC	Application of Integrated gasification combined cycle (IGCC) power plants instead of pulverised-coal-fired (PCF) power plant or standard PC boilers.	n.q. but per power plant it may range from 10 till 25%. Assumed is an overall efficiency from a IGCC plant of 51.7% (LHV)	n.m.	Effectiveness depend on the implementation rate of new plants. Installation of a IGCC instead of a PCF plant reduces CO_2 emission by around 10%. Compared to standard PC boilers it is even 25% reduction. Next to impressive reduction of other substances emitted.	(Baumann et al., 1999)
Facilitate the Launch of an industry that produces CBM via CO_2 injection in the coalbed	H_2 production from coal and methane recovery from deep coal beds using the by-product CO_2 for enhanced coal bed methane (CBM)	n.q. but compared to coal use only enormous reduction of CO_2 can be found (i.e. till factor 6)	2010 - 2020	Other application next to use for transport means are very well possible. A serious benefit from using hydrogen with Fuel-cells is the very little local air emissions.	(Williams 1999)

Policy instrument	Technical measure	Effectiveness [1)]	View year [2)]	Remarks	Reference / study
	recovery, with sequestration of the injected CO_2 in these beds.			CO_2 can also be used at NH_3 plants, which grow seriously because of growing fertiliser demand	
Intervention of industrial policy for improvement of boiler house practice, program for training personnel, facilitate use of relatively diagnostic instruments	Improve industrial boiler efficiency via coal grading, better operating practice and some equipment modifications	63 Mt CO_2 annually	n.m. relatively soon	500.000 industrial boilers are in place in China	(Fang et al., 1999)
International financial and technical help to improve technologies used with utilisation of coal mine methane (CMM). In addition the creating of a well-functioning market mechanism with reasonable pricing is believed important. Also certain favourite policies to CMM should be given.	Update of the technologies used. CMM is drained from the working seams, adjacent seams and surrounding rocks	n.q. but recovery rate is still low, at present namely 21.11%. Therefor serious potential is left.	n.m.	Recovery of CMM is supposed to be more practical above CBM for reason of low permeability of the layers. Per ton of coal 8.43 to 19.89 m^3 of CH_4 can be recovered.	(Xingshan 1999)

1) This is about expected effectiveness.
n.q., means is not quantified

2) n.r., means not relevant
n.m. means is not mentioned