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ZhongXiang Zhang\*

# Energy, Carbon Dioxide Emissions, Carbon Taxes and the Chinese Economy

*Given the global characteristics of climate change and China's potential importance as a source of CO<sub>2</sub> emissions, advocates of controlling CO<sub>2</sub> emissions call for substantial efforts in China. However, the Chinese authorities have argued that China cannot be expected to make a significant contribution to the carbon emission problem unless it receives substantial international aid for this purpose. This contrasts sharply with the wishes of the proponents of controlling CO<sub>2</sub> emissions. This paper is devoted to explaining this difference in opinion by examining some aspects of the Chinese energy system and by analysing the economic implications of possible future CO<sub>2</sub> emissions limits in China.*

At present China contributes 11% of global CO<sub>2</sub> emissions. This means that China ranks second in global CO<sub>2</sub> emissions if the Soviet emissions are distributed over the new independent republics. Given the global characteristics of climate change and China's potential importance as a source of CO<sub>2</sub> emissions, advocates of controlling CO<sub>2</sub> emissions call for substantial efforts in China. However, the Chinese authorities have argued that China cannot be expected to make a significant contribution to the carbon emission problem unless China receives considerable international aid for this purpose. This contrasts sharply with the wishes of the proponents of controlling CO<sub>2</sub> emissions.

Against this background, the project "Compatibility of CO<sub>2</sub> Emission Reduction Targets with Long-term Economic Development in China" was initiated by the Netherlands National Research Programme on Global Air Pollution and Climate Change (NOP). This NOP study is the first systematic and comprehensive attempt to deal with the economic implications of carbon abatement for the Chinese economy in the light of the economics of climate change. This paper summarizes the main findings of the study, with focuses on the analysis of the Chinese energy system and on the macroeconomic analysis of CO<sub>2</sub> emission limits for China.<sup>1</sup>

Because of the low level of exploration for oil and natural gas, the proven recoverable coal reserves in

China are 12.7 times its proven recoverable oil and natural gas reserves combined. At the 1992 levels of production, this will yield a reserves-to-production ratio of 103 years for coal, 22 years for oil and 93 years for natural gas.<sup>2</sup> As for hydropower, the economically exploitable capacity in China is estimated at as much as 378 GW, which is the largest in the world. Because of the lack of investment and unfavourable exploitation conditions, however, hydropower has so far been underdeveloped. The development of nuclear power in China has only just begun. Its domestic uranium supply can meet the need for short-term nuclear power development, but not those of a long-term large-scale development programme if nuclear power stations are to be based on the currently-used pressurized water reactors. With regard to renewables, their role in the energy balance is currently negligible, and there is little prospect of a

<sup>1</sup> In addition to the two topics, the NOP study has also dealt with technological aspects of carbon abatement in China's power industry. In doing so, a technology-oriented dynamic optimization model for power system expansion planning has been developed. Fifteen types of power plants are represented explicitly in the model in terms of their technical, economic and environmental characteristics. Using the model, these plants have first been compared in terms of both the levelized cost of generation and the marginal cost of CO<sub>2</sub> reduction. Then, driven by the baseline electricity demands, the power planning model has been used to develop the baseline scenario for China's electricity supply and to analyse the impacts of compliance with CO<sub>2</sub> limits in the power industry. For a detailed discussion, cf. ZhongXiang Zhang: Integrated Economy-Energy-Environment Policy Analysis: A Case Study for the People's Republic of China, Ph.D Dissertation, Department of General Economics, University of Wageningen, The Netherlands 1996.

<sup>2</sup> The large ratio for natural gas reflects its current low production level because natural gas has historically been considered a low priority in China's energy sector. For a further discussion, cf. ZhongXiang Zhang and H. Folmer: The Chinese Energy System: Implications for Future Carbon Dioxide Emissions in China, in: Journal of Energy and Development, (forthcoming).

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**Table 1**  
**Regional Distribution of Energy Resources, GNP and Energy Use in 1990**  
 (in %)

	North China	Northeast China	East China	Central South	Southwest China	Northwest China
Energy resources	32.3	5.9	9.6	8.5	23.7	20.0
of which:						
Coal	43.2	5.8	11.4	6.2	9.9	23.6
Hydropower	1.2	2.0	3.6	15.4	67.8	9.9
GNP in 1990	13.5	11.7	33.2	25.3	10.6	5.7
Energy use in 1990	18.9	17.5	25.2	19.4	10.9	8.1
of which:						
Coal	22.4	17.8	24.4	17.1	10.9	7.4
Electricity	16.5	15.3	29.0	21.6	9.3	8.3

Sources: State Statistical Bureau: Energy Statistical Yearbook of China, 1991, State Statistical Publishing House, Beijing 1992; State Statistical Bureau: Statistical Yearbook of China 1992, State Statistical Publishing House, Beijing 1992; State Economic and Trade Commission: China Energy Annual Review 1994, Beijing.

dramatic increase because renewable systems are not yet competitive with conventional energy supply. China is thus bound to rely mainly on coal to fuel the development of its economy, and thereby improve the Chinese standard of living, for as far ahead as can be seen.

### Energy Consumption Patterns

Chinese energy consumption patterns can be characterized as follows:

□ *Main reliance on domestic energy resources.* China is self-sufficient in energy. Its entire economy is based on domestic energy resources. Even in the 1950s when oil was imported, 97% of energy supply was still from domestic sources. China's energy balance was also unaffected by the first rise in world oil prices. In 1990, China's energy imports and exports were 13.1 Mtce (Million tons of coal equivalent) and 58.8 Mtce, with the former accounting for 1.3% of total national commercial energy consumption and the latter for 5.7% of total national commercial energy production respectively.<sup>3</sup>

□ *Coal-dominant structure of energy consumption.* China is one of the few countries in the world that relies on coal as its major source of energy. Over the past few years, coal has accounted for more than 75% of primary energy consumption. This share has remained stable after having increased from 70% in 1976. Heavy reliance on coal is to a large extent due to the domestic coal endowments. Restrictions on energy trade also play a role in this massive use of coal.<sup>4</sup> This high proportion of coal consumption leads

to low efficiency of energy use, produces a large amount of CO<sub>2</sub> emissions, and gives rise to serious environmental pollution.

□ *Uneven geographical distribution of energy resources and industry.* As shown in Table 1, 72.6% of existing coal reserves are concentrated in the northern part and 77.7% of exploitable hydropower potential is in the western part, while economically developed regions are located in the south and on the eastern coast. As a result, coal has to be transported over long distances to the load centres. This in turn puts great pressure on the transportation system, especially on the severely congested railways.<sup>5</sup> This uneven geographical distribution also requires a major expansion of the transmission lines and power networks to enable the sending of electricity from the west to the east as well as from the north to the south.

□ *Low per capita energy consumption but high energy use per unit of GNP.* The Chinese per capita

<sup>3</sup> State Statistical Bureau: Energy Statistical Yearbook of China 1991, State Statistical Publishing House, Beijing 1992.

<sup>4</sup> International trade in energy, particularly in oil and natural gas, is controlled by the central government and national self-sufficiency in energy has until now been the policy, which limits the use of oil and gas. Although China's international trade system has already undergone a massive change in recent years, energy trade reform has lagged behind. Nevertheless, as part of China's drive to join the World Trade Organization, the restrictions on international trade in energy are expected to be gradually removed.

<sup>5</sup> In 1989, 43% of the total freight shifted by railways was coal. Cf. H.N. Yang: Coal Transportation System and Assessment of Environmental and Economic Implication in China, in: Environmentally Sound Coal Technologies: Policy Issues and Options, Beijing 1991, pp. 148-156.

commercial energy use in 1990 was 869.5 kgce (kilograms of coal equivalent), only about one-third of the world average, and its energy intensity measured as energy consumption per unit of GNP was 4.43 kgce/US\$ (at the average 1990 exchange rate, 1 US\$ = 4.78 Chinese yuan), among the highest in the world. The former is due to China's low level of development, and the latter reflects an unusually large share of energy-intensive industrial production in the Chinese economy, a large share of energy-intensive manufacturing in China's industry, a high proportion of coal consumption, and the undervaluation of China's GNP. This dual character of energy consumption in China has long been the crux of its energy problems.

□ *Heavy reliance on biomass energy by rural households.* About three-quarters of the energy for domestic use of more than 800 million inhabitants in rural areas depends on biomass energy. In 1990, 215 million tons of firewood were burnt, 75 million tons more than that of the rational felling.<sup>6</sup> This overfelling has caused serious ecological damage to large areas of forest and vegetation.

□ *Industry-dominant composition of final energy consumption.* Since great differences exist between China and the industrialized countries in their economic structures, the compositions of their final energy consumption by sector are also quite different. In China, industry is the dominant energy-consuming sector, accounting for 67.1% of the total in 1990. With the shift towards a less energy-intensive society as the national economy grows, and more energy-efficient industrial utilization, its share is expected to decline slightly in the future. The residential sector is at present the second largest user, consuming about 17% of total final use in 1990, whereas the transport sector consumed only about 5% of the total in 1990. A similar picture applies to electricity consumption; industry consumed 78.2% of electricity production in 1990, the residential sector 7.7%, and the transport sector 1.7%.<sup>7</sup>

### Electricity Generation

China's power industry has been growing rapidly over the past decade in order to cope with the fast growing demand for electricity. During the Seventh Five-year Plan Period (1986-90), the total generating capacity newly added amounted to 50.84 GW, with average annual add-ups of 10 GW. This achievement

meant that total national capacity installed reached 137.89 GW by the end of 1990, thermal power accounting for 73.9% and hydropower for 26.1%. In addition, on 15 December 1991, the first domestically designed and constructed nuclear power unit with a capacity of 300 MW in Qinshan Nuclear Power Station was successfully put into parallel operation with the East China Power Network. This marked the end of an era without nuclear power in China.

Along with a great number of units commissioned into operation, total national electricity generation reached 621.3 TWh in 1990, 100% more than in 1980. Power generated from thermal and hydropower plants accounted for 79.7% and 20.3% of total electricity production respectively. The share of coal-fired plants in total thermal generation rose from 73.6% in 1980 to 89.1% in 1990 as a result of the government policy of replacing oil by coal in power generation in order to release much needed oil into the economy. This share will continuously increase hereafter because oil-fired units will no longer be constructed generally and oil-fired units originally designed for burning oil will be re-converted to coal-fired ones.

Despite the great achievements in electricity generation, China is still a country with a low penetration of electricity in total final energy consumption (TFC). By 1990, the share of electricity in TFC was only 7.6%, considerably smaller than the average for IEA countries (16.6% in 1987) and also below many developing countries e.g. India (15%) and Brazil (19%). Such a small share is one consequence of the small proportion of coal used for electricity generation, which was only 25.8% of total national coal consumption in China in 1990 compared with about 85% in the United States. This implies that coal utilization in China is quite inefficient because the majority of coal is consumed by direct combustion. Moreover, given that coal-fired power stations dominate electricity generation in China, this has led to a very low per capita final electricity consumption, which amounted to only 407 kWh in 1990 compared with 9710 kWh in the United States and 5165 kWh in Japan in 1987.

Some of the problems facing China's power industry are:

□ *Low unit capacity.* Of thermal power capacity installed by the end of 1990, 38.8% comprised units with a capacity of 200 MW and above, 41.5% units

<sup>6</sup> State Planning Commission: *Alternative Energy Supply Options to Substitute for Carbon-Intensive Fuels: A Review of Scenario Analysis*, Beijing 1993.

<sup>7</sup> Cf. State Statistical Bureau: *Energy Statistical Yearbook of China 1991*, op. cit.

with less than 100 MW of capacity, and 19.7% units in between.<sup>8</sup> Compared with a figure of over 60% in the industrialized countries, the share of large units (200 MW and above) in China is quite small.<sup>9</sup> This has led to a high net coal consumption rate of thermal power plants, which averaged 427 gce/kWh in 1990, because the small plants are inferior to large ones in terms of thermal efficiency, capital costs and environmental impacts (cf. Table 2). Thus, major potential gains in terms of economic and thermal efficiency as well as environmental benefits can be realized by installing large units. According to the Ministry of Energy, in future priority will be given to constructing large, high-temperature and high-pressure efficient units generating 300 MW to 600 MW<sup>10</sup> so that by the year 2000 the average national coal consumption rate of thermal power plants will be brought down to 355 gce/kWh, and that for newly commissioned large units should not be higher than 330 gce/kWh.<sup>11</sup>

□ *Underdevelopment of hydropower.* China's hydropower potential is estimated to be the largest in the world, and its economically exploitable capacity totals 378 GW, corresponding to 1920 TWh of annual electricity production. By the end of 1990, however, the total capacity installed of hydropower plants was only 9.5% of the exploitable potential, considerably less than that of the industrialized countries and also below developing countries such as Brazil and India. Given China's abundant hydropower resources, their underdevelopment and their importance as an

alternative to coal use for electricity generation, this current situation means that considerable efforts need to be devoted to speeding up hydropower exploitation in some river sections with favourable exploitation conditions. According to the Ministry of Energy, it is planned that by 2000 China's total hydropower capacity will go up to 80 GW, representing 21.1% of the economically exploitable capacity.

□ *Small share of cogeneration units.* For energy conservation purposes, the Ministry of Energy requires all boilers at places with stable thermal loads and supplying more than 10 t/h for more than 4000 hours per year to be converted to cogeneration. However, the development of cogeneration is hindered by factors such as the high investment costs of the district heat networks, low thermal prices, and some problems in the management system. As a result, the share of cogeneration units in total thermal power capacity installed fell from 20% in 1965 to 10% in 1980 and to 9.8% in 1985. By the end of 1990, this share was only 10.9%, considerably smaller than the 36% of the former Soviet Union in 1980.<sup>12</sup>

□ *Deficiencies of capital investment in transmission lines and distribution networks.* In China power is mainly generated from coal-fired and hydropower

**Table 2**  
**Coal Consumption Rates of Domestically Produced Thermal Power Plants**

Unit capacity (MW)	6	12 ~ 25	50 ~ 100	125	200	300
Net coal consumption rate (gce/kWh)	600	500	391	382	376	376
	800	510	429	386	388	382

Source: ZhaoYi Hu et al.: The Characteristics of China's Energy Supply and Demand and its Countermeasures of Energy Conservation, Electric Power Research Institute, Ministry of Energy, Beijing 1990.

**Table 3**  
**Breakdown of Capital Expenditures for Power**

Share in total capital expenditures for power	Sixth Five-year Plan period	Seventh Five-year Plan period
Hydropower (%)	27.54	18.39
Thermal power (%)	43.19	58.25
Transmission and distribution (%)	20.94	19.29

Source: ZhaoYi Hu: Study on Decision Support Indicator System of Electric Power Industry Development, Electric Power Research Institute, Ministry of Energy, Beijing 1991.

<sup>8</sup> Ministry of Energy: Electric Power Industry in China, Beijing 1991.

<sup>9</sup> ZhaoYi Hu et al.: The Characteristics of China's Energy Supply and Demand and its Countermeasures of Energy Conservation, Electric Power Research Institute, Ministry of Energy, Beijing 1990.

<sup>10</sup> In moving up to large units, however, the possible technological problems should be appropriately addressed. Take the UK experience in adopting 500 MW generating units as an example. Despite considerable experience in operating plants of up to 120 MW, with plant availabilities of over 80% being consistently achieved in the late 1950s and early 1960s, the rapid adoption of successively larger units led to a serious decline in plant availability which, even by 1980, had recovered only to 71%. Cf. Monopolies and Mergers Commission: Central Electricity Generating Board: A Report on the Operation by the Board of its System for the Generation and Supply of Electricity in Bulk, Presented to Parliament in Pursuance of Section 17 of the Competition Act 1980, Her Majesty's Stationery Office, London 1981. Besides, efforts should be directed towards expanding domestic capacity for manufacturing large units, mobilizing the necessary large investment resources, and towards resolving the disappointing performance of domestically-produced large units.

<sup>11</sup> Ministry of Energy: Electric Power Industry in China, Beijing 1992.

<sup>12</sup> ZhaoYi Hu: Study on Decision Support Indicator System of Electric Power Industry Development, Electric Power Research Institute, Ministry of Energy, Beijing 1991; ChengZhang Zhu: The Present Situation of China's Energy Policy and Its Reform, in: China Energy Research Society (ed.): Market Economy and China Energy Development Strategy, Atomic Energy Press, Beijing 1992, pp. 133-140.

plants. Coal reserves and hydropower resources, however, are unevenly distributed geographically. This uneven geographical distribution requires a major expansion of transmission lines and power networks. But capital investment in transmission lines and power networks is insufficient in China, only accounting for about 20% of total capital expenditure in the power industry (cf. Table 3), not only much less than the 65% in the industrialized countries in 1980 but also below the 35% in the developing countries in 1980.<sup>13</sup> As a result, the capability of transmission lines and power networks is insufficient compared with the generating capacity installed. For example, the average annual growth rate of generating capacity installed during the Seventh Five-year Plan period was 9.6%, while the corresponding figure for 35 KV and above level lines was only 6%.<sup>14</sup> The consequences of such a non-matching between power networks and generating equipment capacities have been the weak links in power networks, the high frequency of defects on transmission, substation and distribution equipments, and the unsafety and instability of power networks.

#### **Energy Conservation: An International Perspective**

Energy conservation is of vital importance to China, not only because it saves depletable energy resources and reduces pressure on transportation and environmental pollution, but mainly because severe shortages in energy supply have been inhibiting its economic development. In recent years, China has admitted annual energy shortages (estimates vary) of approximately 20-30 million tons of coal, 10 million tons of petroleum and 70 billion kWh of electricity. Energy shortages contribute to China's claimed 25-30% underutilization of its manufacturing capacity which otherwise might be devoted to increasing a fraction of its GNP.<sup>15</sup> It is estimated that China's energy demand in 2000 will be of the order of 1400-1700 Mtce, even if energy conservation is taken into account, whereas the domestic supply will only be likely to meet 1300-1500 Mtce.<sup>16</sup> Thus, the gap has to be filled through increased efforts directed at energy

conservation and enhanced energy efficiency, if China's development plan is to materialize.

Indeed, the Chinese government has been placing great emphasis on energy conservation in the past decade. A series of measures has been implemented concerning the administrative, legislative, economic and technological aspects of energy policies. Great progress in decoupling its GNP growth and energy consumption has been made, with an annual growth of 8.97% for the former but 5.06% for the latter during the period 1980-90. This achievement corresponds to an income elasticity of energy consumption of 0.56,<sup>17</sup> an accumulated energy savings of 280 Mtce and to an annual savings rate of 3.6%, higher than the planned target of 3%.<sup>18</sup>

While China has enjoyed such a great success, its energy use per unit of GNP is still among the highest in the world. This high energy intensity in China needs to be interpreted with caution however, because the differences between countries in the energy intensities of GNP are not in themselves evidence of economic efficiency or inefficiency in energy use. The high energy intensity in China is partly a reflection of the unusually large share of energy-intensive industrial production in the Chinese economy on the one hand and the unusually small share of the labour-intensive service sector on the other, in comparison with other countries at its income level. For example, 40.6% of China's GDP in 1987 originated from the industry sector and 31.0% from the service sector, while the corresponding figures for India were 28.4% and 40.2% respectively.<sup>19</sup> Moreover, the differing composition of industry affects the levels of energy intensity. Compared with 63.2% for India, China has a larger share of energy-intensive manufacturing in industry that amounted to 80.0% in 1987, thus using more energy than India per unit of industrial output, although the unit energy consumption for major

<sup>13</sup> Cf. ZhaoYi Hu, 1991, op. cit.

<sup>14</sup> Cf. Ministry of Energy, 1991, op. cit.; ChengZhang Zhu, op. cit.

<sup>15</sup> Cf. ZhongXiang Zhang and H. Folmer, op. cit.

<sup>16</sup> Ministry of Energy: Energy in China, Beijing 1989; DeShun Shen et al.: The Strategic Position of Energy Conservation Planning in China, in: China Energy Research Society (ed.): Market Economy and China Energy Development Strategy, Atomic Energy Press, Beijing 1992, pp. 27-31.

<sup>17</sup> The income elasticity of energy consumption in China is quite low by international standards. In addition to energy conservation, there are two other possible explanations for this. First, the growth of energy consumption is underestimated relative to the GNP growth. Second, quantitative restrictions have kept energy consumption from rising as would otherwise have occurred. Drawing on the analysis of rationing by Neary and Roberts, the quantitative restrictions act like an implicit energy tax levied at rates varying with use and fuel. Generally speaking, households face a higher implicit tax than industrial users, and oil and natural gas are taxed at a higher rate than coal. Cf. J. P. Neary and K. W. S. Roberts: The Theory of Household Behaviour under Rationing, in: European Economic Review, Vol. 13, 1980, pp. 25-42.

<sup>18</sup> Cf. DeShun Shen et al., op. cit.

<sup>19</sup> The World Bank: World Tables 1992, The Johns Hopkins University Press, Maryland 1992.

industrial products in China is lower than in India.<sup>20</sup> Also, energy intensity is likely to differ among countries due to differences in resource endowments and in relative resource prices, which suggests that the most economically efficient technology will differ among countries. Given that China is one of the few countries in the world that relies on coal as its major source of energy, its high energy intensity occurs partly as a result of its high proportion of coal consumption, because coal technologies are less efficient than oil/gas technologies. In addition, undervaluation of China's GDP could also be part of the explanation. Some studies show that China's GDP in 1987 calculated on the basis of purchasing power parities (also called real GDP) may reach 7.8 times as much as those calculated directly on the basis of the exchange rate.<sup>21</sup> As a result, China's energy consumption per unit of real GDP is lower than that of all the above-mentioned industrialized countries because there are not many changes in their GDPs calculated on either basis. But it should be pointed out that calculating real GDP is not an easy task, particularly for the centrally planned economies. Thus, the magnitude of China's real GDP mentioned above should be considered only an illustrative figure. Certainly, it is still open to question. Nevertheless, the revised GDP does suggest that if purchasing power parities were used to measure the Chinese economy, China's energy consumption level would not appear that high.

From the preceding analysis, it thus follows that direct cross-country comparison of energy use per unit of output value should by no means be interpreted as representing the actual potential for energy conservation. Indeed, a sector-by-sector comparison of energy intensity in physical terms has shown that China's actual potential of energy conservation is much smaller than that deduced from the direct comparison of energy use with other

countries.<sup>22</sup> Moreover, in order to encourage future energy conservation investment and hence to materialize such a potential, current subsidies for energy consumption in China should be abolished. Also, consideration may be given to appropriate control over the growth of China's energy supply in order to put pressure on energy conservation on the demand side.

### Need for International Assistance

While making such drastic domestic efforts towards energy efficiency, China badly needs assistance and economic and technical cooperation with the industrialized countries, because materializing energy efficiency gain requires increasingly large amounts of capital and technical expertise. Indeed, it is in the direct interest of the industrialized countries to encourage such a take-up, since it will act as a relief of pressure on these countries for yet more stringent measures to reduce CO<sub>2</sub> emissions. This, combined with the commitment made by the industrialized countries at the United Nations Conference on Environment and Development (also called the Earth Summit) in Rio de Janeiro to assist developing countries in reducing their emissions of greenhouse gases, in turn encourages China's request for international assistance.

As past evidence shows, however, multilateral and bilateral development assistance agencies from the industrialized countries as well as international development banks tend to finance large-scale supply-side projects rather than a number of small-scale demand-side ones aimed at promoting end-use energy efficiency improvements.<sup>23</sup> Given the decentralized nature of efficiency projects, the preference for large-scale projects is partly for the sake of reducing administrative overheads. The second reason for the lack of funding for energy efficiency is that some development assistance, especially from bilateral aid agencies, is tied aid, with an official grant or loan offered on the condition that the recipient countries procure goods and services from the donor countries.<sup>24</sup> Clearly, such aid and loan practices are intended to serve the dual purpose both of providing assistance and of expanding exports from the donor countries. Kats<sup>25</sup> has argued that this financial

<sup>20</sup> Cf. Tata Energy Research Institute and Institute of Nuclear Energy Technology: *Energy Development in China and India: A Comparative Study of Energy Supply, Energy Consumption and Energy Policies*, New Delhi and Beijing 1990; The World Bank, *op. cit.*

<sup>21</sup> Cf. A. Shah and B. Larsen: *Carbon Taxes, the Greenhouse Effect, and Developing Countries*, Policy Research Working Papers No. 957, The World Bank, Washington, DC 1992.

<sup>22</sup> For a sector-by-sector comparison of energy intensity in physical terms in China with advanced levels in industrialized countries, cf. ZhongXiang Zhang: *Energy Conservation in China: An International Perspective*, in: *Energy Policy*, Vol. 23, 1995, No. 2, pp. 159-166; ZhongXiang Zhang, 1996, *op. cit.*

<sup>23</sup> Cf. G. Kats: *Slowing Global Warming and Sustainable Development: The Promise of Energy Efficiency*, in: *Energy Policy*, Vol. 18, 1990, No. 1, pp. 25-33; G. Kats: *The Earth Summit: Opportunity for Energy Reform*, in: *Energy Policy*, Vol. 20, 1992, No. 6, pp. 546-58.

<sup>24</sup> For the definitions of tied aid and its impacts on both donor and recipient countries, cf. C.J. Jøpma: *International Policy Coordination and Untying of Aid*, Ashgate Publishing Limited, Aldershot 1994.

<sup>25</sup> Cf. G. Kats, *op. cit.*

assistance pattern is innately biased against energy programmes for promoting energy efficiency improvements in developing countries, since it results in a preference for large-scale projects that are capital-intensive, highly dependent on donor technologies and require major imports in areas of particular export interest to the donor countries.<sup>26</sup> Thus, it is conceivable that developing countries, including China, will be unable to obtain the required funds for this purpose from their industrialized counterparts if this pattern continues. In this case, their achievements in energy conservation will entirely depend on the extent to which domestic efforts are

<sup>26</sup> Cf. C.J. Japma, *op. cit.*

taken and domestic funds are made available for such efforts.

In order to ease the financial constraints and promote the transfers of technology and know-how, third-party financing (TPF), particularly combined with international funding, among other financing mechanisms, has been suggested. By comparison with build-operate-own-transfer (BOOT), which is concerned with investment for expanding energy supply, TPF is concerned with energy conservation by existing energy users.<sup>27</sup> Thus, this mechanism is considered a

<sup>27</sup> Cf. A. Shunker, J.-M. Salles and C. Rios-Velilla: Innovative Mechanisms for Exploiting International CO<sub>2</sub>-Emission Abatement Cost Differences, in: *European Economy*, 1992, Special Edition No. 1, pp. 299-338.

Sabine J. Langner

## The Allocation of Slots in the Airline Industry

### A Transaction Cost Economics Analysis

An increasing number of international airports is congested. To improve the use of scarce airport capacity, so called "slots" have been introduced. A slot represents the right to schedule a flight operation during a specific time interval at a specific airport. Slots are at most airports allocated by the "grandfather" rule, i.e. they are allocated to the incumbent of the prior flight plan period.

This mechanism has been criticized because of lacking allocative efficiency and reduced opportunities for competition. As a remedy it has been proposed to apply social marginal cost pricing or auction off slots. But these suggestions neglect investment in transaction specific capital, the network characteristic of flight services and transaction costs.

To take these factors into account the instruments of transaction cost economics have been applied to the airline industry. Requirements for a slot allocation mechanism are derived from the analysis. It is studied if the currently used mechanisms in the USA and the EU suffice these requirements and whether grandfather airlines have superior bargaining power. Finally, a framework for a slot contract and allocation mechanism is proposed.

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useful means of encouraging the dissemination of energy conservation schemes. Related to this, joint implementation projects for increased energy efficiency should be encouraged.<sup>28</sup> Moreover, insofar as the bulk of infrastructure and capital equipment in developing countries has still to be put in place in the course of their industrialization, developing countries, including China, still have considerable leeway in choosing their development paths. In this regard, the industrialized countries can play a very active role. They can act in a number of ways. For example, they can provide assistance in facilitating joint ventures. This can help their companies profit from China's booming economy, and at the same time can help the Chinese companies employ more advanced foreign technology, thus using energy more efficiently.

**Historical CO<sub>2</sub> Emissions**

Total CO<sub>2</sub> emissions from fossil fuels in China rose from 358.60 MtC (Million tons of Carbon) in 1980 to 586.87 MtC in 1990, with an average annual growth rate of 5%.<sup>29</sup> This means that China ranks second in global CO<sub>2</sub> emissions if the Soviet emissions are distributed over the new independent republics. But on a per capita basis, China's CO<sub>2</sub> emissions of 0.5 tC in 1990 were very low by comparison with the world average. With regard to the breakdown of CO<sub>2</sub> emissions by fuel, not surprisingly, coal predominates, accounting for 83.4% of the total emissions in 1990.

Regarding contributions to the growth of CO<sub>2</sub> emissions over the period 1980-90, Figure 1 clearly indicates that China's economic growth measured in per capita GDP was an overwhelming factor, resulting alone in an increase of 314.67 MtC. Population

<sup>28</sup> The concept of joint implementation has been built into the Framework Convention on Climate Change (FCCC) to allow countries to invest in emission reduction projects in other countries where such projects would be more cost-effective than trying to achieve an equivalent reduction within their own countries. According to Article 4.2(a) of the FCCC, which states that the developed country Parties and other Parties included in Annex I (the Annex I countries are the OECD and Eastern European countries) may implement ... policies and measures jointly with other Parties and may assist other Parties in contributing to the achievement of the objective of the Convention, however, the G-77 and China have argued that joint implementation should be applicable to Annex I Parties only. Recognizing that joint activities to address climate change issues are different from joint implementation, a compromise achieved in the first Conference of the Parties in Berlin in 1995 was the decision to establish a pilot phase for activities implemented jointly among Annex I Parties and, on a voluntary basis, with non-Annex Parties (i.e. developing countries). This clarified the debate on which countries would be eligible for joint implementation arrangements. Cf. C.J. J e p m a (ed.): The Feasibility of Joint Implementation, Kluwer Academic Publishers, Dordrecht 1995; Joint Implementation Quarterly, Vol. 1, 1995, No. 1.

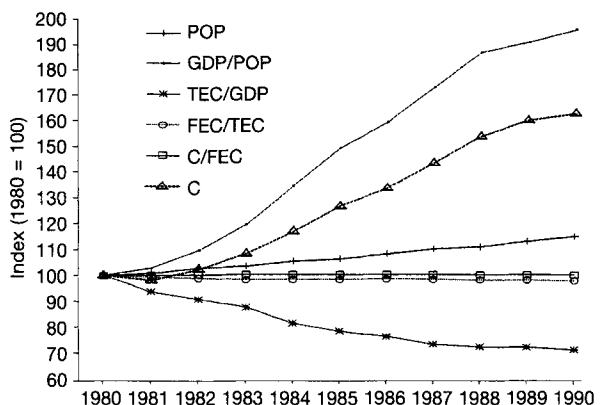
<sup>29</sup> The data used in this section are taken from ZhongXiang Zhang and H. Folmer, op. cit.

expansion was responsible for an increase of 68.27 MtC, which is considered to be modest given the population size. The change in fossil fuel mix contributed to an increase of 5.33 MtC because the share of coal use in total commercial energy consumption was slightly increased during the period. By contrast, a reduction of 154.67 MtC was achieved because of great success in energy conservation. The penetration of carbon-free fuels also contributed to a small reduction in emissions. This is mainly due to the underdevelopment of hydropower, and partly because no nuclear power stations were commissioned during that period.

**Environmental Challenges**

Driven by the threat of further degradation of the environment and the harmful economic effects of energy shortages, China is already determined to make great efforts towards energy conservation and enhanced energy efficiency in general, and towards using coal much more efficiently in particular. A number of policy measures, which have been and will continue to be implemented, have been outlined. They are the so-called "no-regrets" measures in the sense that they are taken without considering the greenhouse effect. These measures include an increase in the proportion of raw coal washed; the retrofitting and replacement of small inefficient industrial boilers; substituting the direct burning of

**Figure 1**  
**Contributions to CO<sub>2</sub> Emissions in China, 1980-90**



C = the amount of CO<sub>2</sub> emissions.

FEC = the total carbon-based fossil fuel consumption.

TEC = the total commercial energy consumption.

GDP = Gross Domestic Product.

POP = the population.

Source: ZhongXiang Zhang and H. Folmer: The Chinese Energy System: Implications for Future Carbon Dioxide Emissions in China, in: Journal of Energy and Development, (forthcoming).

coal by electricity through the development of large-size, high-temperature and high-pressure efficient coal-fired power plants; speeding up hydropower exploitation; popularizing domestic use of coal briquettes; increased penetration of town gas into urban households; expanding district heating systems; and relaxing restrictions on energy trade. Moreover, success in the implementation of these measures will largely depend on the extent to which a reform of China's energy pricing is carried out. With respect to reducing CO<sub>2</sub> emissions, because the "regrets" policies are often costly, "getting prices right" and implementing the "no-regrets" actions listed above should have priority over the imposition of a carbon tax, indicating that the implementation of these measures will be accelerated if curbing global CO<sub>2</sub> emissions requires special action on China's part.

### Macroeconomic Analysis of CO<sub>2</sub> Emission Limits

In analysing the economic impacts of limiting CO<sub>2</sub> emissions, it has been argued that a CGE (Computable General Equilibrium) approach is generally considered an appropriate tool.<sup>30</sup> Thus, a time-recursive dynamic CGE model of the Chinese economy has been developed for such a purpose. The main features of the CGE model for China are as follows.<sup>31</sup>

This CGE model operates by simulating the operation of markets for factors, products and foreign exchange, with equations specifying supply and demand behaviour across all markets. The model includes ten producing sectors and distinguishes four energy inputs. The CGE model is made up of the following nine blocks: production and factors, prices, income, expenditures, investment and capital accumulation, foreign trade, energy and environment, welfare, and market clearing conditions and macroeconomic balances. The model allows for endogenous substitution among energy inputs and alternative allocation of resources as well as endogenous determination of foreign trade and household consumption in the Chinese economy for coping with the carbon limits at both sectoral and macroeconomic levels. The model is also able to calculate the resulting welfare impacts. Furthermore, the CGE model incorporates an explicit tax system. This makes it

suitable for estimating the "double dividend" from the imposition of a carbon tax that is incorporated as a cost-effective means of limiting CO<sub>2</sub> emissions.<sup>32</sup>

### The Baseline Scenario

Using this CGE model, a baseline scenario for the Chinese economy has been developed under a set of assumptions about the exogenous variables. The baseline scenario is characterized by a rapid growth of the Chinese economy, with GNP being expected to grow at an average annual rate of 8.34% for the period from 1990 to 2000 and 7.55% thereafter to 2010. Consequently, this will lead to increased energy consumption and hence CO<sub>2</sub> emissions, despite substantial energy efficiency improvement. As shown in Table 4, the baseline CO<sub>2</sub> emissions are expected to grow from 586.9 MtC in 1990 to 898.9 MtC in 2000 and to 1441.3 MtC in 2010 at an average annual rate of 4.4% for the period to 2000 and 4.8% thereafter to 2010. The slightly accelerated growth of CO<sub>2</sub> emissions during the second period is partly because economic growth, although somewhat slower in this period, still remains strong, and partly because of the reduced energy conservation rate as well as no significant change in the coal-dominated pattern of energy consumption.

On a per capita basis, China's energy consumption of 0.86 tce in 1990 is expected to rise to 1.19 tce in 2000 and to 1.80 tce in 2010, while the corresponding CO<sub>2</sub> emissions of 0.5 tC in 1990 are expected to rise to 0.7 tC in 2000 and to 1.0 tC in 2010. Although the figures are doubled over twenty years, they are still well below the corresponding current world average levels, which were equal to 2.12 tce and 1.14 tC respectively in 1990.<sup>33</sup>

### The Two Less Restrictive Scenarios

Using the time-recursive dynamic CGE model and assuming that carbon tax revenues are retained by the government, the economic implications of two

<sup>30</sup> Cf. ZhongXiang Zhang and H. Folmer: Economic Modeling Approaches to Cost Estimates for the Control of Carbon Dioxide Emissions, in: *Energy Economics*, (forthcoming); ZhongXiang Zhang, 1996, op. cit.

<sup>31</sup> For a detailed description of the CGE model for China, cf. ZhongXiang Zhang, *ibid.*

<sup>32</sup> A carbon tax is more cost-effective in terms of target achievement than an energy tax. Moreover, compared with an energy tax, a carbon tax is less burdensome in that it raises a smaller amount of government revenues for a given reduction of CO<sub>2</sub> emissions. Cf. ZhongXiang Zhang and H. Folmer: The Choice of Policy Instruments for the Control of Carbon Dioxide Emissions, in: *INTER-ECONOMICS*, Vol. 30, 1995, No. 3, pp. 133-142; ZhongXiang Zhang, 1996, op. cit.

<sup>33</sup> The world average levels of energy consumption and CO<sub>2</sub> emissions have been calculated based on data from Dean and Hoeller and British Petroleum. Cf. A. Dean and P. Hoeller: Costs of Reducing CO<sub>2</sub> Emissions: Evidence from Six Global Models, in: *OECD Economic Studies*, 1992, No. 19, pp. 15-47; British Petroleum: *BP Statistical Review of World Energy*, London 1993.

scenarios, under which China's CO<sub>2</sub> emissions in 2010 will be cut by 20% and 30% respectively relative to the baseline, have been analysed. The two emission targets are less restrictive in that they are not compared with the level of emissions in a single base year, but with the baseline CO<sub>2</sub> emissions in 2010, the latter being 2.46 times those in 1990. The main findings are as follows.

First, a larger absolute cut in CO<sub>2</sub> emissions will require a higher carbon tax. A higher tax also implies higher prices of fossil fuels (cf. Table 5). Moreover, carbon tax rises at an increasing rate as the target of CO<sub>2</sub> emissions becomes more stringent, indicating that large reductions in carbon emissions can only be achieved by ever-larger increases in carbon taxes and hence prices of fossil fuels.

Second, even under the two less restrictive carbon emission scenarios, as shown in Table 5, China's GNP drops by 1.5% and 2.8% and its welfare measured in Hicksian equivalent variation drops by 1.1% and 1.8% respectively in 2010 relative to the baseline, indicating that the associated GNP and welfare losses tend to rise more sharply as the degree of the emission reduction increases. Given the often reported losses of 1-3 per cent of GDP in industrialized countries under very restrictive carbon limits, the results also support the general finding from global studies that China would be one of the regions hardest hit by carbon limits. This, combined with the

industrialized countries' being responsible for the majority of global CO<sub>2</sub> emissions, explains the Chinese government stance in carbon abatement.

Third, although aggregate gross production tends to decrease at an increasing rate as the carbon dioxide emission target becomes more stringent, changes in gross production vary significantly among sectors in both absolute and relative terms. Of the ten sectors considered, we found that the coal sector is affected most severely in terms of output losses under the two CO<sub>2</sub> constraint scenarios. Consequently, this will lead to a considerable decline in the sector's employment. Thus, special attention should be paid to the sectoral implications when designing a domestic carbon tax.

Fourth, although a change in the level and structure of economic activity and a change in direct energy consumption by households play some role in reducing total energy consumption, lower energy input coefficients contribute to the bulk of energy reduction and hence CO<sub>2</sub> emissions in 2010 under the two CO<sub>2</sub> constraint scenarios. With respect to the contributions to carbon abatement in 2010, although in relative (percentage) terms energy consumption in the coal sector and the corresponding CO<sub>2</sub> emissions in 2010 are reduced most under both scenarios, in absolute terms, the largest reductions occur in the heavy industry.

**Table 4**  
**Energy-Related Results for the Baseline Scenario**

	1990	2000	2010
Energy consumption (Mtce)	987.0	1546.4	2560.4
Energy consumption per capita(tce)	0.86	1.19	1.80
Coal (Mt)	1055.2	1578.9	2418.2
Coal's share in total energy consumption (%)	76.2	72.9	67.5
Electricity (TWh)	623.0	1395.7	2745.2
Energy intensity of GNP (kgce/yuan)	0.717	0.504	0.403
Elasticity of energy consumption w.r.t. GNP <sup>a,b</sup>	0.56	0.55	0.68
Elasticity of electricity consumption w.r.t. GNP <sup>a,b</sup>	0.84	1.01	0.93
Average annual rate of energy conservation (%) <sup>a</sup>	3.6	3.46	2.21
CO <sub>2</sub> emissions (MtC)	586.9	898.9	1441.3
CO <sub>2</sub> emissions per capita (tC)	0.51	0.69	1.01

<sup>a</sup> w.r.t. is short for with respect to.

<sup>b</sup> The figures in 1990 are for the period 1980 - 1990, in 2000 for the period 1990 - 2000, and in 2010 for the period 2000 - 2010.

Source: ZhongXiang Zhang: Integrated Economy-Energy-Environment Policy Analysis: A Case Study for the People's Republic of China, Ph.D Dissertation, Department of General Economics, University of Wageningen, The Netherlands 1996.

**Table 5**  
**Main Macroeconomic Results for China in 2010**  
(Percentage Deviations Relative to the Baseline; -: Declines)

	Scenario 1	Scenario 2
GNP	-1.521	-2.763
Welfare <sup>a</sup>	-1.078	-1.753
Private consumption	-1.165	-2.972
Investment	-0.686	-1.832
Exports	-5.382	-7.447
Imports	-1.159	-2.128
Energy consumption	-19.468	-29.322
CO <sub>2</sub> emissions	-20.135	-30.112
Price elasticity of carbon abatement	-0.396	-0.317
Price of coal	64.954	123.095
Price of oil	15.296	29.144
Price of natural gas	46.813	90.564
Average price of fossil fuels	50.888	94.895
Price of electricity	22.785	43.256
Terms-of-trade	3.636	3.822
Nominal wage rate	-1.807	-3.043
Real exchange rate	-0.004	-0.021
User price of capital	-1.777	-4.228
Prices of exports	3.633	3.801
Prices of imports	-0.004	-0.021

<sup>a</sup> Measured in Hicksian equivalent variation.

Source: cf. Table 4.

**Carbon Tax Revenue Recycling Scenarios**

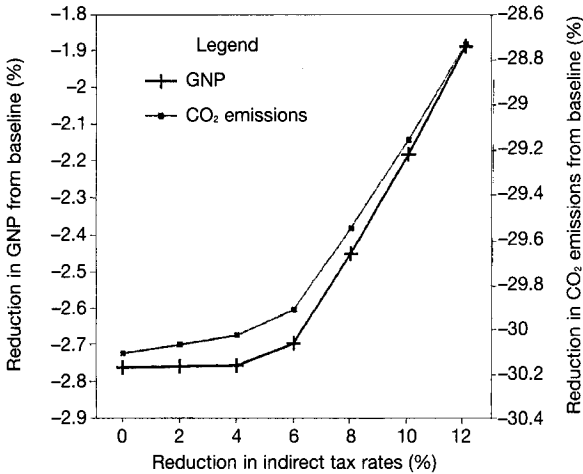
Imposing a carbon tax will raise government revenues. How these revenues are used will affect the overall economic burden of the tax. Zhang and Folmer<sup>34</sup> and Zhang<sup>35</sup> have argued that the macroeconomic effects of offsetting carbon tax revenues with reductions in indirect taxes are more positive than in other tax offset cases. Thus, this will probably be the most likely use of the revenues. We have computed the efficiency improvement of four indirect tax offset scenarios relative to the two tax retention scenarios above. The first two tax reform scenarios maintain the carbon tax of Scenario 1, but indirect tax rates for all sectors are equally reduced by

5% and 10% respectively. Similarly, the last two tax reform scenarios maintain the carbon tax of Scenario 2, but indirect tax rates for all sectors are equally reduced by 5% and 10% respectively.

The four simulations show that if these revenues were used to offset reductions in indirect taxes, the negative impacts of carbon taxes on GNP and welfare would be reduced. Moreover, as shown in Figures 2 and 3, the efficiency improvement tends to rise as the target of CO<sub>2</sub> emissions becomes more stringent (i.e. fossil fuels are taxed more heavily by carbon taxes). This suggests that it would become more worthwhile to lower indirect taxes in order to reduce the adverse effects of a carbon tax.

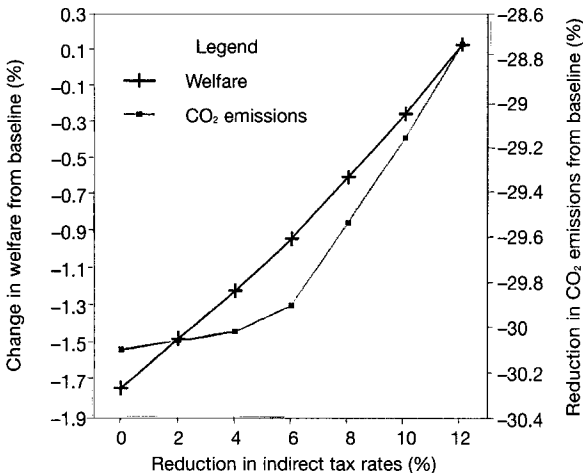
**Figure 2**

**GNP Effect of Indirect Tax Offset Relative to Scenario 2**



**Figure 3**

**Welfare Effect of Indirect Tax Offset Relative to Scenario 2**



**Comparison with other Studies for China**

A comparison with the well-known global studies based on GLOBAL 2100 and GREEN with respect to China has been made.<sup>36</sup> From Table 6 it can be seen that our estimates of the reduction in GNP growth are higher than those by GLOBAL 2100 and GREEN in order to achieve the same reductions in CO<sub>2</sub> emissions relative to the baseline. This difference might be related to three factors. First, our baseline of carbon emissions is higher than that in GLOBAL 2100 and GREEN, indicating a larger gap between uncontrolled emissions and a particular target in our study and hence the higher costs incurred for compliance with the target. Second, our model is relatively disaggregated compared with both GLOBAL 2100 and GREEN. This implies less substitutability in our model, leading to higher economic costs. Third, model types matter. While in our single-country model one branch of industry is estimated to be negatively affected under the carbon constraints, this would not always be the case in a global model such as GREEN because of the relative improvement in Chinese branch goods' competitiveness via trade reallocation. The differing effects brought about by the imposition of unilateral carbon taxes or regional carbon taxes could be part of the explanation for the higher GNP losses in our model.

<sup>34</sup> Cf. ZhongXiang Zhang and H. Folmer: The Choice of Policy Instruments for the Control of Carbon Dioxide Emissions, op. cit.

<sup>35</sup> Cf. ZhongXiang Zhang, 1996, op. cit.

<sup>36</sup> For a detailed description of GLOBAL 2100 and GREEN, cf. A.S. Manne and R.G. Richels: Buying Greenhouse Insurance: The Economic Costs of CO<sub>2</sub> Emission Limits, The MIT Press, Cambridge, Massachusetts 1992; J.M. Burniaux, J.P. Martin, G. Nicoletti and J.O. Martins: GREEN - A Multi-Sector, Multi-Region General Equilibrium Model for Quantifying the Costs of Curbing CO<sub>2</sub> Emissions: A Technical Manual, Working Papers No. 116, Department of Economics and Statistics, OECD, Paris 1992.

**Table 6**  
**A Comparison of CO<sub>2</sub> Emission Reductions,  
 Carbon Taxes and Growth  
 Effect across Models in 2010**

	CO <sub>2</sub> emissions <sup>a</sup>	Carbon tax <sup>b</sup>	GNP (GDP) <sup>c</sup>
GLOBAL 2100 <sup>e</sup>			
Scenario 1%	-18.036	57.999	-0.783
Scenario 2%	-32.657	165.837	-2.127
Scenario 1	(-20.135)	(73.480)	(-0.976)
Scenario 2	(-30.112)	(147.066)	(-1.893)
GREEN <sup>e</sup>			
Scenario 1%	-17.535	8.000	-0.200
Scenario 2%	-32.135	20.000	-0.500
Scenario 1	(-20.135)	(10.137)	(-0.253)
Scenario 2	(-30.112)	(18.337)	(-0.458)
Our CGE model			
Scenario 1	-20.135	17.929	-1.521
Scenario 2	-30.112	34.983	-2.763

<sup>a</sup> Percentage deviations relative to the corresponding baseline (-: declines).

<sup>b</sup> Measured in US dollars per ton of carbon. In GLOBAL, carbon taxes are measured at 1990 prices, in GREEN at 1985 prices, and in our model at 1987 prices.

<sup>c</sup> The figures in parentheses result from interpolating the carbon taxes required and the associated GDP losses that have originally been estimated by GLOBAL 2100 and GREEN in order to achieve the same carbon reductions as those in our study.

Sources: A. S. Manne: Global 2100: Alternative Scenarios for Reducing Carbon Emissions, Working Papers No. 111, Department of Economics and Statistics, OECD, Paris 1992; J. O. Martins, J. M. Burniaux, J. P. Martin and G. Nicoletti: The Costs of Reducing CO<sub>2</sub> Emissions: A Comparison of Carbon Tax Curves with GREEN, in: OECD: The Costs of Cutting Carbon Emissions: Results from Global Models, Paris 1993, pp. 67-94; ZhongXiang Zhang: Integrated Economy-Energy-Environment Policy Analysis: A Case Study for the People's Republic of China, Ph. D Dissertation, Department of General Economics, University of Wageningen, The Netherlands 1996.

**Table 7**  
**Carbon Taxes across Regions in 2010**  
 (in 1985 \$ per Ton of Carbon)<sup>a</sup>

	USA	Japan	EEC	Total OECD	China	World
Scenario 1%	39	46	71	48	8	34
Scenario 2%	139	116	180	152	20	105
Scenario 1	(53.4)	(55.9)	(85.7)	(62.7)	(10.1)	(45.1)
Scenario 2	(120.3)	(103.1)	(158.6)	(132.3)	(18.3)	(92.9)

<sup>a</sup> The figures in parentheses result from interpolating the carbon taxes required and the associated GDP losses that have originally been estimated by GREEN in order to achieve the same carbon reductions as those in our study.

Sources: J. O. Martins, J. M. Burniaux, J. P. Martin and G. Nicoletti: The Costs of Reducing CO<sub>2</sub> Emissions: A Comparison of Carbon Tax Curves with GREEN, in: OECD: The Costs of Cutting Carbon Emissions: Results from Global Models, Paris 1993, pp. 67-94; ZhongXiang Zhang: Integrated Economy-Energy-Environment Policy Analysis: A Case Study for the People's Republic of China, Ph. D Dissertation, Department of General Economics, University of Wageningen, The Netherlands 1996.

With respect to the carbon taxes required to achieve the same carbon reductions in 2010 relative to the baseline, our estimates are on the one hand higher than those by GREEN. This is because GREEN has a smaller gap between the uncontrolled emissions and the emission target, and because GREEN has lower baseline prices of fossil fuels. On the other hand, our estimates are lower than those by GLOBAL 2100. This is because GLOBAL 2100 assumes lower rates of autonomous energy efficiency improvement, and because GLOBAL 2100 considers limited options for reducing CO<sub>2</sub> emissions and overstates the costs of some important alternative low carbon-polluting energy technologies.<sup>37</sup>

Comparing the carbon tax levels across the regions considered in Table 7 with those in Table 6, we can see that the carbon taxes required in China are much lower than those for both the industrialized countries and the world average in order to achieve the same emission reductions relative to the baseline. These significant differences in carbon tax levels across regions point to opportunities for international trade in carbon emission permits to reduce the global costs of abating CO<sub>2</sub> emissions. However, it is unlikely that a global regime of tradeable carbon permits will emerge in the near future. Thus, as a preliminary step towards that regime, the joint implementation mechanism, although not without conceptual problems, should be considered a means of reducing global CO<sub>2</sub> emissions effectively.<sup>38</sup> This mechanism will not only help China, which is becoming an important source of future CO<sub>2</sub> emissions, alleviate the suffering from possible future carbon limits, but also act to lower the costs of undertaking carbon abatement in the industrialized countries that are currently responsible for the majority of global CO<sub>2</sub> emissions and hence to reduce the competitive disadvantage and carbon leakage associated with purely unilateral policies in these countries. Worldwide, this will achieve global carbon abatement at a lower overall cost than would otherwise have been the case.

<sup>37</sup> Cf. R.H. Williams: Low-Cost Strategies for Coping with CO<sub>2</sub> Emission Limits (A Critique of 'CO<sub>2</sub> Emission Limits: An Economic Cost Analysis for the USA' by Alan Manne and Richard Richels), in: The Energy Journal, Vol. 11, 1990, No. 3, pp. 35-59.

<sup>38</sup> In practice, making the joint implementation mechanism operational will depend on far-reaching negotiations with respect to additional funds rather than traditional development aid, access to funding, comprehensiveness, baseline definition, crediting, minimum levels of domestic abatement targets, costs, technology transfers, risk, and institutional arrangements. For a detailed discussion of this mechanism, cf. T. Jones: Operational Criteria for Joint Implementation, in: OECD: The Economics of Climate Change, Proceedings of an OECD/IEA Conference, Paris 1994, pp. 109-125; C.J. Jepma, 1995, op. cit.