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ANALYSIS

The CO_2 emission reduction benefits of Chinese energy policies and environmental policies: A case study for Shanghai, period 1995–2020

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Abstract

The international literature has paid much attention to so-called ‘fringe benefits’ of greenhouse gas (GHG) policies. The concept is that GHG emission reduction in developing countries will also reduce local air pollution. On the basis of this concept, it is argued that it is possible to achieve simultaneously a reduction of local air pollution and a reduction of greenhouse gas emissions. In reality, however, there is a sequence to the policy agenda. First the apparent local air pollution problems are tackled then the more distant greenhouse gas problem is considered. This sequence has consequences for the optimal policy selection. Moreover, most studies that focus on fringe benefits of GHG policies neglect the existence of cost-effective dedicated abatement technology for local air pollutants. This paper analyses the optimal set of policies for reduction of SO_2, NO_x and CO_2 in Shanghai for the period of 2000–2020. The analysis is based on a linear programming MARKAL model for the Shanghai energy system. The results show that the relevance of no-regret options is limited because Shanghai has improved its energy efficiency significantly in recent years. The model calculations suggest that this trend will persist if current policies are sustained. This energy efficiency improvement and the planned introduction of natural gas have important benefits from a GHG emission point of view. These benefits have received little attention as yet. Local air pollution reduction can result in additional GHG emission reduction up to 2010. After 2010, however, its CO_2 emission co-benefits are limited. Dedicated abatement technology is the most cost-effective way to reduce local air pollution. An additional incentive of 100 Yuan/t CO_2 emission reduction (12.5 Euro/t) results in an additional emission reduction of 11% (22 Mt CO_2), and it results in a significantly different technology mix than stand-alone local air pollution policies. The total potential for GHG emission reduction amounts to 66 Mt in 2010 and to 49 Mt in 2020 compared to base case levels without policies. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

China is the country with the largest population in the world. Its energy use has been increasing rapidly during the last two decades because of the phenomenal economic growth of 8–10% per year. If this economic growth persists, Chinese energy consumption will represent an increasingly significant fraction of global energy consumption. As a consequence, future developments in China are of great importance to the future of the global energy system and its related environmental impacts.

The most important Chinese energy resource is coal. Coal use represents approximately 73%[2] of the total primary energy use, the remainder being oil and, to a much lesser extent, hydro, nuclear, and natural gas. Coal use is the source of a number of environmental problems. Local pollution problems related to coal use, such as sulphur dioxide (SO_2) emissions and particulate matter (pm) emissions, are well-known, e.g. (Qian and Zhang, 1998). Recently, nitrogen oxides (NO_x) have emerged as a local air pollution problem in cities due to rapidly increasing oil consumption in road transportation. In recent years, the carbon dioxide (CO_2) emissions that are related to Chinese coal use have received much international attention.

The international literature has paid much attention to so-called 'fringe benefits'[3] of greenhouse gas (GHG) policies (see for example, Ekins, 1996; WRI, 1997; Wang and Smith, 1999). The concept is that certain options for GHG emission reduction in developing countries will simultaneously reduce local air pollution. The benefits of local air pollution reduction are very significant. As a consequence, greenhouse gas emission reduction can be obtained with low additional costs. This argument is used to plead for a reduction of GHG emissions in countries such as China. In reality, however, the order of issues on the policy agenda is different. First the apparent local air pollution problems are tackled; next the more distant GHG problem is considered. Therefore, it is more relevant to study the impact of local air pollution abatement on GHG emission reduction than vice versa. Moreover, most studies that focus on fringe benefits of GHG policies neglect the existence of cost-effective abatement technology for local air pollutants that does not have a positive effect on GHG emission (e.g. SO_2 scrubbers for coal-fired power plants). As a consequence, the GHG emission mitigation effects of local air pollution reduction can be questioned. The goal of this paper is to identify the optimal set of air pollution mitigation policies by taking a broader perspective (i.e. options with multiple benefits versus options with single benefits).

The Chinese government has developed ambitious plans for reducing China's dependency on coal in favour of other energy sources such as natural gas, as well as increasing the efficiency of energy use. These policy plans have been driven by strategic considerations and by concerns regarding local air pollution. Up to now, any CO_2 emission reduction target has been rejected. However, the energy policy plans and strategies aiming for local air pollution reduction will also affect CO_2 emissions. This paper will answer the following questions:

- What is the impact of planned Chinese energy policies on GHG, SO_2 and NO_x emissions?
- What is the impact of a significant reduction of local air pollution on GHG emissions?
- What would be the cost-effectiveness of a GHG emission reduction policy on top of these two policies?

This paper is based on a case study for the city of Shanghai. This coastal metropolis has approximately 16 million residents, the size of a small country such as, e.g. the Netherlands. This indi-

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[2] The figure is reduced to 62% if straw and firewood are included (non-commercial energy carriers).

[3] The terms 'co-benefits', 'auxiliary benefits' or 'secondary benefits' are also used.

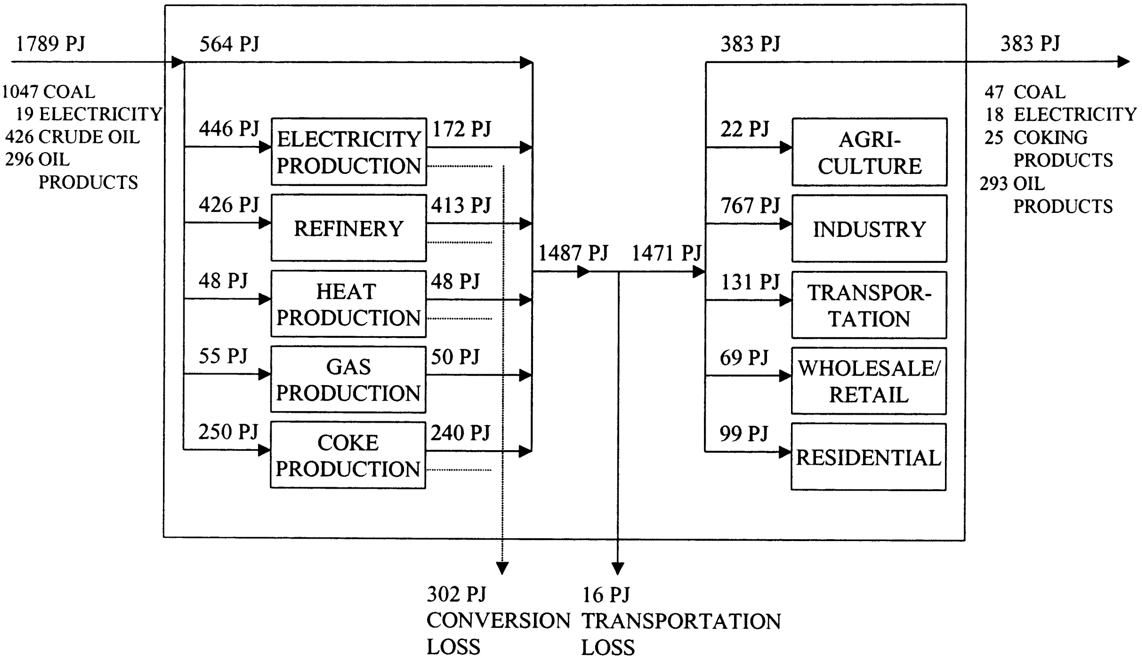

Fig. 1. Structure of the Shanghai energy system, 1998.

cates the relevance of the case study from a global GHG emission perspective.

Since 1990, total energy consumption in Shanghai has been increasing at an average annual rate of 5.7%. The energy system structure for 1998 is shown in Fig. 1. In the last decade the share of coal in total energy consumption has been increasing to 70% of energy consumption. Industry accounts for 70% of total primary energy consumption, the living needs of the residents for only 8%.[4] Power generation accounts for 48.3% of coal consumption, coke making and gas generation for 24.1% and direct combustion for 24.3%. Energy imports amounted to 1789 PJ and exports amounted to 383 PJ in 1998 (the exports consist mainly of oil product shipments from the coastal refineries to the interior of China). Note that conversion losses from primary to final energy in Fig. 1 amount to 318 PJ (including transportation losses), the bulk of which (274 PJ) is accounted for by electricity production. Especially the losses in refining, heat production and coke production seem rather low in comparison to process energy efficiency data for other countries. This difference can be explained by the different definitions in Chinese energy statistics, where (part of) the process energy of the conversion processes (the energy for process furnaces) is accounted for in the category 'final industrial energy use'.

Energy efficiencies for Shanghai are illustrated in Table 1. Comparisons with other regions are complicated by the fact that the energy services are generally not exactly the same (for example, the average cars are smaller than in the US, TV sets have a smaller screen, power production is based on coal instead of natural gas). Moreover, climatic differences and differences in equipment use complicate a proper comparison. However, the data in Table 1 suggest that there is some potential left for energy efficiency improvement. Note that the figures in Table 1 are only indicative; generally speaking there is a lack of proper

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[4] 'Secondary industry' in Chinese energy statistics includes all energy use for manufacturing and for power generation, thus residential use excludes electricity use. The service sector is called 'tertiary industry', agriculture is called 'primary industry'.

Table 1
Comparison of energy efficiency in Shanghai and in OECD countries, 1998

Application	Unit	Shanghai	OECD countries
Coal-fired electricity production	(GJ el/GJ fuel)	0.38	0.40–0.44
Primary steel production	(GJ/t)	20–25	18–20
Oil refining	(GJ/GJ)	0.03	0.03–0.07
Ethylene production	(GJ/t)	65	55–60
Coal-fired industrial boilers 4–10 t steam/hr	(GJ steam/GJ fuel)	0.65	0.7–0.75
Passenger cars	(l/100 km)	10	8–14
Colour TV	(W)	100–150	70–120
Air conditioner	(kW cold/kW el)	3.6–4.4	3.8–5.5

well-documented energy efficiency data for China. The data presented are based on interviews with local energy experts, matched by data from energy statistics.

2. The methodological approach

Given the rapid changes in the Chinese energy system with regard to the demand structure, technology, and policy objectives, econometric models are inadequate for proper long-term analysis. Detailed system engineering models are a better tool in order to gain proper insight into the interactions of these variables in case of changing energy supply and changing energy demand. The MARKAL (MARKet ALlocation) optimisation model has been used in this study.

The MARKAL model was developed 20 years ago within the international IEA/ETSAP framework (International Energy Agency/Energy Technology Systems Analysis Programme). Nowadays more than 50 institutes in 27 countries use MARKAL (ETSAP, 2000). A MARKAL model is a representation of (part of) the economy of a region. The economy is modelled as a system, represented by processes and physical and monetary flows between these processes. These processes represent all activities that are necessary to provide products and services. Many products and services can be generated through a number of alternative (sets of) processes that are based on different technologies, with different costs and different environmental impacts (e.g. incandescent lighting vs. compact fluorescent lighting). The model covers all processes that are relevant from an energy and emission point of view, and calculates the least-cost system configuration. In this study the emissions considered are carbon dioxide CO_2, methane CH_4, sulphur dioxide SO_2 and nitrogen oxides NO_x. The model algorithm can represent the 'market forces' or a 'perfect regulator', and is obviously an abstraction. The optimal system configuration is characterised by process activities and flows.

The model user can define the process database and the constraints. Constraints are determined by the demand for products and services that have to be met by the energy system, the maximum introduction rate of new processes, the availability of resources, and environmental policy goals for energy use and for emissions, etc. Processes are characterised by their physical inputs and outputs of energy and material, by their costs, and by their environmental impacts. Environmental impacts can be internalised in the process costs and the costs of energy and material flows between processes (and are thus considered in the selection of processes). Alternatively, an upper emission limit (a constraint) can be defined in order to represent a policy target. The process alternative with the lowest costs will be selected in the optimal model configuration.

The time span to be modelled is divided into nine periods of equal length, generally covering 5 years/period. In this case the period 1995–2035 has been considered (1995 and 2035 are the mid-period years of the first and last period). The model is used to calculate the least-cost system configuration for the whole time period, meeting externally defined product and service demands and emission reduction targets. This optimisation is based on a so-called 'perfect foresight' approach, where all time periods are simultaneously optimised. Future constraints are taken into account in current investment decisions. In this study, a discount rate of 12% has been applied, based on Anderson and Williams (1994). This high discount rate reflects the fact that China is a developing country, where high uncertainty regarding future development must be reflected in the discount rate.[5]

The model covers 22 energy carriers, 20 materials and 150 processes, and the system must satisfy 24 demand categories. The technology data have been derived from Chinese technology studies. In some sectors, foreign sources had to be used to complete the data set. The technology selection has been limited to 'proven technology' in order to achieve maximum policy relevance. This includes technologies that are currently not yet widespread in advanced countries such as the US (e.g. hybrid vehicles, fuel cell cars). The same applies for integrated gasifier combined cycles (IGCC for electricity production from coal), Corex (iron production) and Hycon (refining sector). This shows that there is ample room for technological change in the model. Technologies such as nuclear fusion, fuel cell systems for power generation, computer systems to control residential energy use, etc. have not been included because we consider these technologies unfeasible in the short term. The development and large-scale introduction of new technology is a slow process which takes decades. The evaluation of technology assessment studies in the last decades shows that any claims in literature regarding upcoming dramatic changes are very unlikely; see e.g. (Olsson, 2000).

The database is characterised briefly in Table 2. The model has been calibrated with municipal energy statistics and environmental data for 1995. Trends since 1995 have been used to calibrate the model for the year 2000.

Costs for emission reduction (in Yuan/t emission reduction) are only one dimension in the selection of policy strategies. The potential effectiveness of emission reduction (in kt emission reduction for the whole city) is another important parameter. For example, it is comparatively cheap to use low-NO_x burners, but these burners achieve a maximum emission reduction of 40–50%. If 80% emission reduction is aimed for, this measure is not adequate. Other measures (e.g. selective catalytic reduction SCR) that can achieve an 80% emission reduction result in higher average costs for emission reduction. Both dimensions are considered in the MARKAL optimisation.

Certain measures reduce different kinds of emissions simultaneously. For example, if natural gas is introduced as a substitute for coal, CO_2, NO_x and SO_2 emissions are reduced at the same time. The actual 'benefit' for each emission type depends on the emission targets per emission category or it depends on the damage per (marginal) tonne of emission. Only an aggregated comparison of costs and benefits is sensible in such a case. In MARKAL terms, the benefits are accounted for on the basis of the marginal emission reduction costs. The characteristics of the emission mitigation options have been taken from literature (e.g. Halkos, 1995; Dings, 1996; Arai, 1997).

3. Policy plans and policy simulations

3.1. *Shanghai energy policies*

Shanghai municipality has recently drafted a plan for sustainable development, including energy and environmental policies (Shanghai Municipality, 1999). The total coal consumption will

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[5] Note that a lower discount rate is not necessarily beneficial from an environmental point of view. For example, the competitiveness of coal-fired power plants increases versus gas-fired power plants in case of lower discount rates because the investment costs for gas-fired power plants are significantly lower. However, the environmental impacts of coal-fired power plants are much more serious. On the other hand, a lower discount rate increases the relevance of future damage caused by GHG emissions, which would be an argument in favour of natural gas. However, the estimation of such long-term effects is a formidable problem beyond the scope of this study. Instead GHG emissions are valued based on previous studies, (see Section 3.2). The uncertainty regarding the extent of future damage caused by GHG emissions is probably much higher than the uncertainty regarding the discount rate.

Table 2
Characterisation of the model database

Sector	Technologies/sectors	Sources
Power plants	Coal, Gas, co-generation (CHP), hydro import (3 gorges dam), nuclear, renewables	Interviews with local experts, (Chandler et al., 1998), (Logan and Luo, 1999), (Torrens and Stenzel, 1997), (Perrels and Lako, 1998)
Industry	Steel, petrochemicals, other boilers, other motors, pumping, office equipment, lighting	Interviews with local experts, (Daniels and Moll, 1997), (Groenendaal and Gielen, 1999), (Beijing Energy Efficiency Center, 1995), (IIEC, 1999), (Yang et al., 1996), (Zhou et al., 1997)
Transportation	Passenger cars, trucks, scooters, others	Interviews with local experts, (Cannon, 1998), (Dempsey, 1999), (Environmental Resources Management, 1998), (Malakoff, 1999), (Mao et al., 1999), (Tang, 1999)
Residential	Air conditioners, lighting, refrigerators, cooking, others	(Chen, 1999), (Kaita, 1998), (Liu, 1993), (Liu et al., 1996), (Min et al., 1997) (Ybema et al., 1995)

be kept below 50 Mt by 2005 and 48–50 Mt by 2010. As a consequence, the proportion of coal in primary energy will drop to less than 55%. No new power plants will be built in the urban area, gradually switching to power imports. The total capacity of coal-fired power plants in the municipality will not exceed 12 GW.[6] Shanghai has secured 3 GW electricity imports from the Three Gorges Dam and the nuclear plant at Qinshan. The share of natural gas in primary energy consumption will reach 10–12% by 2010 as a result of liquefied natural gas (LNG) imports and some gas import from the East China Sea. This gas will substitute for residential and commercial coal gas use. The construction of new coal-fired boilers in areas inside the Inner Ring will be prohibited. As a matter of principle, no more coal-fired boilers will be built in city-level industrial development zones (Shanghai Municipality, 1999).

In order to improve energy efficiency, boilers, kilns and furnaces will be renovated. Co-generation will be promoted in areas where annual load reaches 4000 h. Gas air-conditioners, solar boilers and passive solar energy will be promoted. Rational energy use will be promoted in general.

Beside energy policies, demographic policies and transportation policies must also be considered. For example, the number of registered residents will be controlled at 15.5 million in 2005 and 16 million in 2010. At the same time, the migrant population increases from 2.37 million in 1997 to 3.5–4 million in 2010. These growth

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[6] The current level is approximately 7 GW.

Table 3
Characterisation of model cases

Model run	Acronym	Cost effective efficiency/fuel switch	Constraint maximum 50 Mt coal/year	SO_2, NO_x emission constraint	CO_2 reduction incentive
Base case	BC	X			
Energy policy	EP	X	X		
Local environmental policy	LEP	X	X	X	
Sustainability policy	SP	X	X	X	X

figures are important because they will also affect the demand for energy services, energy use and the related emissions.

Shanghai environmental policy has decided to limit SO_2 emission to 450 kt/year in 2005 and to 420 kt/year in 2010 (Shanghai Environmental Protection Bureau, 1998). Shanghai does not yet have NO_x emission control policies.

3.2. Policy simulations

Four cases have been compared (see Table 3). The policy ambitions increase from top to bottom in Table 3. In the base case (BC), cost-effective efficiency improvements and cost-effective fuel switches are introduced.

In the energy policy case (EP), the coal use is limited to 50 Mt/year (1050 PJ/year) for the whole period beside the cost-effective measures. In the case of SO_2 and NO_x policies (LEP), SO_2 emissions are limited to 250 kt/year from 2005 onward (a reduction by more than 50%). NO_x emissions are reduced to 250 kt in 2005 (a reduction by 35–40%) and decrease further to 200 kt/year in the next two decades. These local air pollution policies are added to the energy policies. Note that the constraints exceed current policy targets with regard to local air pollution reduction. More ambitious targets have been analysed because the current emission levels are very high and the fringe benefits become clearer in case of an ambitious target (in other words, they are a reflection of significant external effects).

In the sustainability policy case (SP), a CO_2 emission reduction incentive of 100 Yuan/t CO_2 (approx. 12.5 EURO/t) is added from 2005 onward (based on Weyant and Hill, 1999; Criqui et al., 2000; Sijm et al., 2000). This incentive represents the value of GHG emission reduction in a global market. For example, such a value represents a realistic subsidy paid by foreign countries in the framework of the clean development mechanism (CDM).

4. Results

A selection has been made from the model results, focusing on three levels:

- Energy use and emission trends for the whole city of Shanghai, 1995–2020.
- The impact of policies on the sector emissions, 2020.
- The impact of policies on technology selection, focusing on electricity supply.

These three levels will be discussed separately in Sections 4.1, 4.2 and 4.3. The latter two levels illustrate the mechanisms that drive the trends for the whole city, which are discussed in Section 4.1.

4.1. Energy use and emission trends for the whole city of Shanghai

Table 4 shows the results of energy use and emissions of CO_2, SO_2 and NO_x for the four policy cases for the years 1995, 2010 and 2020. Based on these data, two indexes have been calculated, which are also shown. The first one is the trend for 2010 and 2020, compared to 1995 levels (1995 = 1.00). Energy use and emissions for indi-

Table 4
Energy use and emission trends in the four policy cases, 1995–2020

Case		Unit	1995	2010	2020	2010/1995	2020/1995	Case/BC 2020
BC	Energy	(PJ/year)	962	1615	1800	1.68	1.87	1.00
	CO_2	(Mt/year)	133	196	208	1.47	1.56	1.00
	SO_2	(kt/year)	524	581	672	1.11	1.28	1.00
	NO_x	(kt/year)	280	467	475	1.67	1.69	1.00
EP	Energy	(PJ/year)	962	1559	1678	1.62	1.74	0.93
	CO_2	(Mt/year)	133	185	177	1.39	1.33	0.85
	SO_2	(kt/year)	524	529	539	1.01	1.03	0.80
	NO_x	(kt/year)	280	453	421	1.62	1.50	0.89
LEP	Energy	(PJ/year)	962	1496	1669	1.56	1.73	0.93
	CO_2	(Mt/year)	133	169	181	1.27	1.36	0.87
	SO_2	(kt/year)	524	250	250	0.48	0.48	0.37
	NO_x	(kt/year)	280	247	228	0.88	0.81	0.48
SP	Energy	(PJ/year)	962	1420	1615	1.48	1.68	0.90
	CO_2	(Mt/year)	133	130	159	0.98	1.20	0.76
	SO_2	(kt/year)	524	250	250	0.48	0.48	0.37
	NO_x	(kt/year)	280	247	229	0.88	0.82	0.48

vidual policy cases show different trends. The second index compares energy use and emissions in the policy cases in 2020 with energy use and emissions in the base case (BC = 1.00). This index shows the impact of policies in 2020 compared to autonomous trends.

BC shows almost a doubling of energy use between 1995 and 2020. This base case includes a significant cost-effective increase in energy efficiency throughout the energy system. Emissions increase at a much lower pace than energy use. CO_2 emissions increase by 56%, SO_2 emissions increase by 28% and NO_x emissions increase by 69%. The divergence between energy use and CO_2 emissions (31% in 25 years) is caused by a partial switch from coal to gas and oil and increased import of electricity. This switch is caused by structural change (a larger than average growth in the transportation sector), policies (no new coal-fired boilers in industry) and market mechanisms (substitution of town gas by cheaper natural gas). The total impact of energy efficiency improvements amounts to an emission reduction of up to 20 Mt CO_2.[7] This 10% reduction shows that the relevance of no-regret options is limited because Shanghai has improved its energy efficiency significantly in recent years. The SO_2 emission trends are closely related to trends in coal use, while the NO_x emission growth is closely related to trends in the transportation sector (see also Section 4.2).

EP shows a 15% decline of CO_2 emissions compared to the BC in 2020. Total energy use is reduced by 7%. Due to the maximum constraint on coal use, more gas is introduced. Gas use efficiency is generally higher than coal use efficiency. Moreover, the remaining coal is used with greater efficiency due to introduction of new technology. The reduction of CO_2 emissions indicates the important contribution of local energy policies to long-term GHG emission reduction. SO_2 emissions are virtually stabilised at 1995 levels, while NO_x levels increase by 50% compared to 1995 levels.

LEP shows a strong decline of CO_2 emissions in 2010 compared to EP. However, this effect has disappeared in 2020. Given the inherently more environment-friendly character of new technology, the long-term impact of local air pollution policies on GHG emissions is negligible. The technological change is discussed in more detail in Section 4.2.

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[7] Estimated on the basis of energy efficiency difference between existing technology and new technology introduced before 2020 in the model database.

SP shows a decline of CO_2 emissions by 23% in 2010 and 17% in 2020 compared to LEP. The emission reduction is substantial in both years, but the larger emission reduction in 2010 shows that some of the GHG policies accelerate the introduction of new technologies which would have been introduced by market forces anyway, but at a later stage. This is an important issue to be addressed when the GHG benefits of CDM projects are estimated. A long time horizon is required in order to prevent an overestimation of emission reduction benefits. The impact on local air pollution levels is negligible compared to LEP. This suggests that a GHG policy on top of an ambitious policy focusing on local air pollutants offers no additional benefits to local air pollution levels.

A comparison of costs and benefits of the policy scenarios is provided in Table 5. The costs refer to the annualised system costs in 2020. The benefits have been split into CO_2 reductions and other emissions. The reason for this split is a different valuation method. The global estimates of CO_2 emission reduction benefits vary widely. The value of emission reduction credits in a CDM system (100 Yuan/t, see Section 3.2) has been used as an approximation. SO_2 reduction and NO_x reduction have been valued on the basis of estimates for Shanghai from a study of the World Bank (1997) and estimates of WRI (1999) at a value of 5000 Yuan/t emission reduction. The emission reductions can be derived from Table 4. The resulting benefits minus costs suggest in all policy cases a significant increase of welfare. However, many caveats must be added. The most important is probably that the bulk of the benefits will arise for other individuals than those that have to bear the costs. Also the value of benefits is subject to substantial uncertainty (at least one order of magnitude). However, given the very considerable difference between costs and benefits, this suggests that ambitious environmental policies make sense in the case of Shanghai.

In conclusion, current energy policy plans will have important environmental benefits on a local level and even on a global level. The technologies with multiple benefits are more costly than the measures with only local emission benefits. As a consequence, the international community should pay for the cost difference if they want additional GHG benefits. This will have important consequences for the optimal investment strategy. For example, in the electricity sector LEP results in the selection of coal gasification, while gas-fired power plants are optimal in the SP case (see below). A switch from one technology to the other implies complete replacement of costly capital goods. As a consequence, timely participation is recommended in order to prevent a sub-optimal technological ‘lock in’. In case such a lock in occurs, the costs of additional CO_2 policies will be significantly higher because, for example, new coal-fired power plants cannot switch to gas. As a consequence such plants would have to close down before the end of their technical life and be replaced by gas-fired power plants, resulting in significantly higher costs. The costs will be in excess of the added costs for LEP and SP. In fact, such a scenario could make the CO_2 reductions uneconomical. Especially if the additional transaction costs of CDM are considered, which are not accounted for in the model, such a situation is not unlikely. Timely participation is essential in order to achieve maximum environmental benefits at minimum costs.

Table 5
Comparison of emission reduction costs and emission reduction benefits, 2020

Case	Costs (MY/year)	Benefits CO_2 red. (MY/year)	Benefits SO_2/NO_x red. (MY/year)	Benefits-costs (MY/year)
EP	100	3100	935	3935
LEP	700	2700	3345	5345
SP	1700	4900	3340	6540

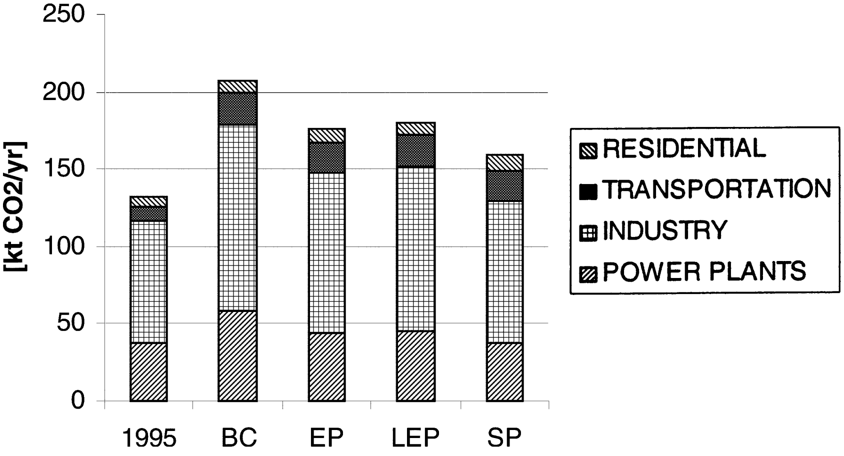

Fig. 2. The impact of policies on the sector CO_2 emissions, 2020.

4.2. Impacts on sector emissions

The preceding analysis focused on the aggregated energy system level. The following discussion will focus on the changes at sector level and at process level. The CO_2, SO_2 and NO_x emission trends for the four policy cases are elaborated in Figs. 1–3. Each figure shows the sector emissions in 1995 and the emissions in 2020 for increasingly ambitious policy targets.

Fig. 2 shows the results for CO_2. BC emissions increase in all sectors compared to 1995 levels. Industry remains the most significant emission source. The emission reduction in the policy cases is mainly achieved in industry and in electricity production.

Fig. 3 shows the results for SO_2. The main increase in BC emissions, compared to 1995 levels, occurs in electricity production, representing over 60% of all emissions. Major emission reduction is also achieved in electricity production in case environmental policies are introduced. Emissions in electricity production are reduced by more than 90% in the LEP case due to introduction of desulphurisation technology. Fig. 5 below shows the changes that take place in electricity production. IGCC is introduced as a substitute for the supercritical steam cycle and the ultra-supercritical steam cycle. Small-scale industrial natural gas combined heat and power (CHP) systems substitute for natural gas based combined cycles.

Fig. 4 shows the results for NO_x. Compared to 1995 levels, emissions in BC increase mainly in the transportation sector and they increase to a lesser extent in electricity production. In the EP case some emission reduction is achieved in electricity production. However, the most important emission reduction occurs in the LEP case. The bulk of NO_x emission reduction is achieved in the transportation sector and in power production (see Fig. 3). New technologies include a 3-way catalyst for gasoline vehicles, hybrid cars and IGCC power plants. The introduction of additional CHP systems increases the efficiency of coal use, which reduces the demand for coal-fired industrial boilers. Yet 90% of the emission reduction is accounted for by the introduction of IGCC.

4.3. Impacts on technology selection in electricity supply

The results in Section 4.2 have shown the importance of developments in the electricity sector for future emissions. The results for power production are elaborated in more detail in this section. Fig. 5 shows the electricity production for the four cases in 1995 and in 2020.

The results show that electricity production has more than doubled between 1995 and 2020. In the BC this increase is accounted for by high efficiency coal-fired power plants and by coal-fired co-generation of electricity and heat CHP for industry. Electricity from nuclear and hydro sources is imported. In the EP case gas and imports increase at the expense of coal. In case local air pollution policies are added (LEP), then coal gasification is introduced. Natural gas, imports and some renewables increase further in the SP case at the expense of coal.

5. Conclusions and outlook

Because of the strong economic growth and the heavy reliance on coal, CO_2 emissions in Shanghai are predicted to increase by 47% in 2010 and by 56% in 2020 in the base case without policy targets. This base case includes cost-effective increases in energy efficiency in the whole energy system and introduction of natural gas in the residential sector as a substitute for town gas. The total impact of efficiency improvements amounts up to 20 Mt CO_2 emissions. This 10% reduction of CO_2 emissions shows that the relevance of no-regret options is limited because Shanghai has already improved its energy efficiency significantly in recent years. This result conflicts with previous studies such as (Liu, 1993; WRI, 1997) that identified a significant potential for no-regret emission mitigation in China. However, investments in the last decade have largely been based on comparatively efficient technology. Old efficiency figures do not apply to this new equipment. On the other hand, Shanghai is probably not representative for the whole of China. The main emission mitigation potential may be located in the rural areas where energy efficiency policies are less developed and the investments in new capital equipment are at a much lower level.

Due to energy policies and local air pollution reduction policies, CO_2 emissions will decrease by up to 24% in 2020 compared to base case emission levels. This figure shows the important contribution of other Chinese policies to GHG emission reduction, a fact that has received little attention as yet in global emission reduction policy making. Local air pollution reduction can accelerate the introduction of GHG emission reduction to 2010. However, given the inherently more environment-friendly character of new technology, its long-term impact on CO_2 emission reduction will be limited after 2010. This is an important result to be considered in the discussion of secondary benefits of GHG policies. The results suggest that dedicated emission mitigation technology (without or with limited GHG benefits) is a more cost-effective way to reduce local air pollution. Examples are 3-way catalysts for cars and IGCC for electricity production. Such technologies should be considered if secondary benefits are valued (a ‘marginal costing’ principle).

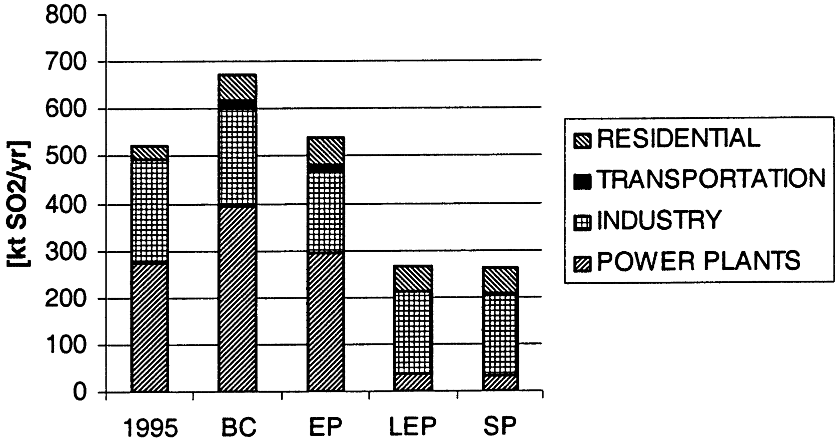

Fig. 3. The impact of policies on the sector SO_2 emissions, 2020.

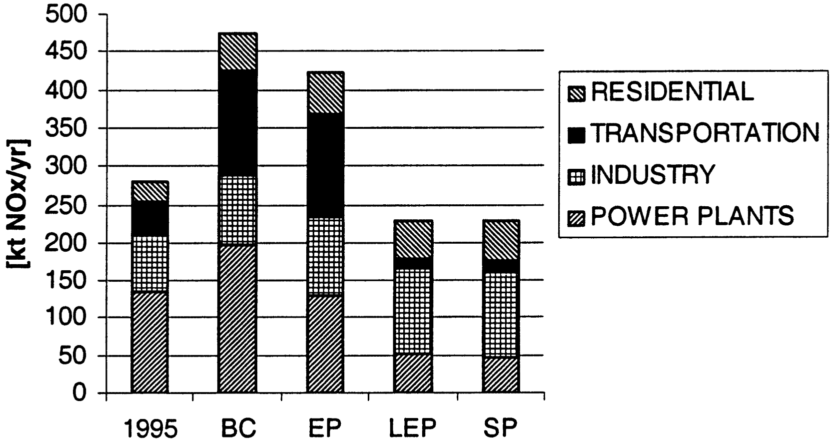

Fig. 4. The impact of policies on the sector NO_x emissions, 2020.

An additional incentive of 100 Yuan/t CO_2 results in an additional emission reduction of 11% (22 Mt CO_2). This incentive is well in the range of predictions for emission permit prices in case of a global GHG permit market. This opens up a prospect for international co-operation, e.g. based on CDM mechanisms.

In conclusion, the total potential for GHG emission reduction in 2010 amounts to 66 Mt and to 49 Mt in 2020 compared to base case levels without policies. These quantities are very significant. The Netherlands, for example, has a policy target in the framework of the Kyoto commitment for 2008–2012 of 25 Mt GHG emission reduction abroad. This entire emission reduction could be achieved in co-operation with one single Chinese city. Still, a proper definition of a reference scenario for emission reduction is crucial in order to prevent any free rider effects, resulting in sub-optimal allocation of GHG reduction funds. For example, the environmental policies that have been formulated will also reduce CO_2 emissions significantly. In case these CO_2 reductions are labelled as CDM projects, the actual environmental benefits of CDM are, in fact, negligible. Given the phenomenal growth of the Chinese economy, and emission levels in Shanghai that are approaching levels in industrialised countries, it seems reasonable that some of the financial burdens are borne by the Chinese side. It is recommended that the LEP policy case be used as reference level, thus still leaving a CDM potential of 39 Mt CO_2 emission reduction in 2010 and 22 Mt emission reduction in 2020.

The costs of the local air pollution policies are limited. As a consequence, financing such policies is an issue of secondary importance. Where conventional technologies such as 3-way catalysts are concerned, regulation may suffice (i.e. the polluter pays principle). In case of investments in new innovative technologies such as gasification, there is still a substantial risk that technological prob-

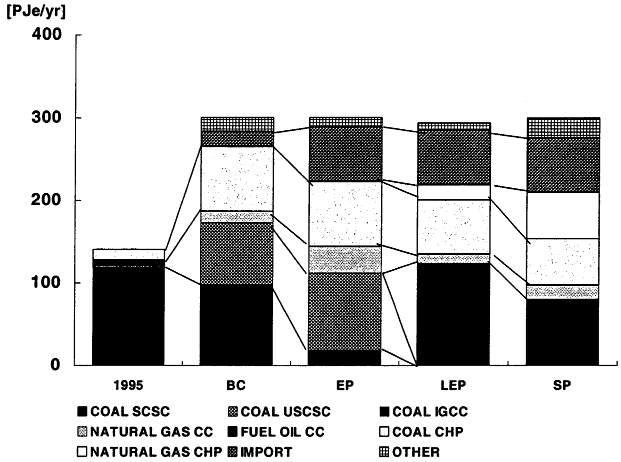

Fig. 5. Electricity supply structure, 2020 (SCSC, supercritical steam cycle; USCSC, ultra-supercritical steam cycle; IGCC, integrated gasifier and combined cycle; CHP, combined heat and power generation).

lems will occur. This may deter private financing of such projects. Given that the scope of such technological breakthroughs extends to the whole of China, and to other countries, it is recommended that the Chinese national government or the World Bank assist in the financing of such projects.

Of course, the modelling study is subject to many inherent uncertainties; the rate of economic growth and demographic change; the assumptions regarding structural economic change and Chinese technology characterisation all affect the result to some extent. The building of the liquefied natural gas terminal in Shanghai is still in the feasibility study stage (Ma, 2000). On the other hand, a pipeline is being considered that will provide gas from Xinjiang (Oil and Gas Journal, 2000). The future of both projects will determine gas availability.

The study results are based on a cost optimisation model with rational decision-making, an obvious abstraction from decision making in the complex real world. Important pollutants such as particulate matter have not been considered in the analysis. In the next stage of the project, these aspects will be considered in more detail in order to refine the model. The study will be finalised in the summer of 2001.

Another issue within this study is the relevance of these results for other Chinese cities and for the Chinese national level. More case studies are planned in the framework of the EU three cities project, where similar MARKAL models are being developed for Tianjin and Chongqing (Jansen, 2000). A similar MARKAL model is currently being developed for Beijing (Lu, 2000). The results from these additional case studies will show whether Shanghai is representative for the other Chinese cities. The additional results are expected in the summer of 2001.

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