China Green Input-output Accounting:

Coal, Efficiency of Power Generation and Green House Gas Emissions (1992–2020)

COMPTABILITE DES ENTREES ET SORTIES VERTE DE LA CHINE :

CHARBON, EFFICACITE DE LA GENERATION D'ENERGIE ET EMISSION DES GAZ A EFFET DE SERRE (1992-2020)

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Abstract: While energy is a required factor in any kind of economic activity, most environmental problems, such as acid rain precipitation, greenhouse-gas emissions, and exhaustion of nonrenewable resources, seem to be related to overuse of primary energy. It is therefore important to consider energy within the framework of an integrated analysis of natural resources, economy, and the environment. In recent years, many scholars have studied this issue (see, for example, Balistreri & Rutherford, 2000; Jiang, 2002; Lin & Polenske, 1995; Xu et al.,2002; Zhang & Folmer, 1997) in the light of different but traditional input-output models.

One kind of theoretical green input-output table, focused on energy, is designed on the basis of our Green Input-output Accounting Framework of Natural Resources-Economy- Environment. Scenario forecasting and analysis for China in 2020 are made. Coal used, without further transformation, mainly for power generation, is the major source of SO_2 and CO_2 emissions in China, and it will remain so without changes to the final and intermediate demand structures.

Key words: Green input-output accounting, energy, structure and efficiency, scenario analysis

Résumé: Quand l'énergie devient un facteur nécessaire pout toute sorte d'activité économique, la plupart des problèmes environnementaux, tels que la pluie acide, l'émission des gaz à effet de serre, l'épuisement des ressources nonrenouvelables semblent se rapporter avec l'abus de l'énergie primaire. Donc il est important de considérer le problème d'énergie dans le cadre de l'analyse intégrée des ressources naturelles, l'économie et l'environnement. Dans les dernières années, beaucoup savants ont étudié ce problème (voir, par exemple : *Balistreri & Rutherford, 2000; Jiang, 2002; Lin & Polenske, 1995; Xu et al.,2002; Zhang & Folmer, 1997)* à la lumière de différents mais rationnels modèles des entrées et sorties.

Une sorte de tableau des entrées et sorties vert, concentré sur l'énergie, est conçu sur la base de notre Cadre de la Comptabilité des Entrées et sorties Verte des Ressources Naturelles-Economie-Environnement. On a déja prévu et analysé le scénario de la Chine en 2020. Le charbon utilisé, sans autre transformation, principalement pour la génération énergitique , constitue la source majeure de l'émission de SO_2 et CO_2 en Chine, et cette situation va subsister sans aucun changement dans les structures de demande finale et intermédiaire.

Mots-Clés: comptabililté des entrés et sortie verte, structure et efficacité, analyse du scénario

While energy is a required factor in any kind of economic activity, most environmental problems, such as acid rain precipitation, greenhouse-gas emissions, and exhaustion of nonrenewable resources, seem to be related to overuse of primary energy. It is therefore important to consider energy within the framework of an integrated analysis of natural resources, economy, and the environment. In recent years, many scholars

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have studied this issue (see, for example, Balistreri & Rutherford, 2000; Jiang, 2002; Lin & Polenske, 1995; Xu et al.,2002; Zhang & Folmer, 1997) in the light of different but traditional input-output models.

In this paper, I develop a new green input-output model for linkage analysis of natural resources, energy, the economy, and the environment based on my Green Input-output Accounting Framework of Natural Resources-Economy-Environment (see Lei, 1995, 1996a, 1999a & b, 2000a, 2003), and I formulate a scenario forecast and analysis for the integrated natural resources-energy- economy-environment situation for China from 1992 to 2020.

This paper has seven sections. In section 1, I design a kind of green input-output accounting theoretical table integrating natural resources-energy-economy-environment. In section 2, such a table is actually compiled based on the Chinese input-output table and *Chinese Statistical Year Books* (see State Statistical Bureau of China, 1993-02; and 1996). In section 3, I make an elementary analysis of the relationships in China between natural resources, energy, the economy and the environment. In section 4, a green input-output model is developed. Then I design six different scenario assumptions and explain the origin of the data in section 5. In section 6, I anticipate according to these 6 scenarios some likely outcomes for the period 1992–2020. In section 7, I propose some conclusions for China's sustainable development problems.

1. GREEN INPUT-OUTPUT ACCOUNTING TABLE FOR NATURAL RESOURCES-ENERGY-ECONOMY-ENVIRONMENT

On the basis of my former work (see Lei, 1995, 1996 a&b, 1997, 1999 a & b, 2000a&b, 2001, 2002, 2003), I designed a green input-output accounting table of integrating natural resources, energy, the economy and environment (GIO table) (see table 1).

This table is a mixed physical-value and unbalanced input-output table in which there are two characteristics in contrast with Leontief's environmental IO table (see Leontief et al., 1972) and others' input-output tables: First, my GIO is an unbalanced input-output tables; second, it is based on the marginal opportunity cost (MOC) theory (see Lei, 1995, 1996a, 1999 a & b, 2000a, 2003; Pearce and Markandya, 1989).[1]

In the rows of the table, "inputs" are extended from the traditional productive consumption, which corresponds to marginal product cost (MPC), to full consumption, corresponding to the marginal opportunity cost (MOC) or the marginal social cost (MSC).

MOC is composed of marginal product cost (MPC), marginal environmental cost (MEC), and marginal user cost (MUC). MPC refers to labor, capital, and other traditional intermediate product inputs. MEC refers to the loss [degradation/depletion] in environmental ecology caused by human activities. MUC refers to the use [depletion/degradation] of natural resources in human activities. [2]

My General Input-Output (GIO) table is designed in light of the three parts of MOC. [3] More specifically:

1.1 Physical resource input (usage)/consumption (in physical units) is classified according to the kinds of natural physical resources used (e.g., coal, petroleum, natural gas, forests, etc.) and indicated by the amount of exhaustion/usage of physical resources in the process of human activities.

1.2 Production input/consumption (in monetary units) is similar to the input in the traditional input-output table, which consists of intermediate product input and primary input (e.g., salaries, depreciation of fixed assets, taxes, operational surplus).

1.3 Environmental resource input (damage)/consumption (in physical units) is classified according to the kind of pollutants emitted (e.g., CO_2, SO_2, No_x) and indicates the amount of pollutants emitted in the process of human activities.[4]

In the rows of the table, the "sector" is extended from the traditional productive sector to three different sectors—resource-recovery, production, and pollution-abatement sectors. The resource- recovery sector is classified by the corresponding kind of physical resources used in the process of human activities. Each sector corresponds to one concrete kind of resources used. The production sector's classification is the same as that in the traditional table. The pollution-abatement sector is classified according to the corresponding kind of pollution emission. Each sector corresponds to one concrete pollutant emitted.

Correspondingly, final output and total output in this GIO table are also extended to three parts. The first part (corresponding to resource usage/consumption) and the third part (corresponding to pollution emission) are separately indicated by the amount of natural resource used/consumed and the amount of pollution emission in the whole process of human activities, respectively. The second part is indicated as in the traditional input-output table.

Furthermore, in order to consider energy production and consumption in particular, the traditional production/industrial sector in this GIO table is further divided into three parts: 1) primary energy sector; 2) secondary energy sector; 3) other. The corresponding input is also divided into three parts: 1) primary energy products; 2) secondary energy products; 3) other products (see table 1).

There are two other characteristics that differ with the IO table in the United Nations' System of Environmental and Economic Accounting (SEEA) (see

United Nations et al., 2003; 2000; 1993). First, in this GIO table, not only are the "inputs" extended from traditional production input to natural resources input, production input, and environment input, but the "sectors" are extended from the traditional production sector to the natural-resources-recovery, production, and pollution-abatement sectors. Second, the GIO table is a closed table from the point of view of its flow (see Lei, 1995, 1996a, 1999 a & b, 2000a, 2003).

2. BASIC GREEN INPUT-OUTPUT TABLE OF CHINA

Based on the Chinese input-output table and the Chinese *Statistical Year Book,* we set up GIO table of China on the basis of the theoretical table 1.[5]

In this specific GIO table, there are:

- Three kinds of natural resources: coal, petroleum and natural gas (unit: 10,000 tons)

- Five energy-production sectors: coal mining and processing (Coa), petroleum and natural gas extraction (Cnfgas), power generation, steam and hot water production and supply (Ele), petroleum processing (Tpr), coking gas and coal-related products (Coke) (units: million tons of oil equivalent)

- thirteen non-energy production sectors: farming, forestry, animal husbandry, fishery and water conservancy (1); food, beverages, and tobacco (6); textiles (7); paper-making and paper products (10); chemicals and allied products (14); building materials and other (15); smelting and pressing of metals (16); machine building, electric and electronic equipment (18–21); other manufacturing (qtgye); construction (25); transportation, post and telecommunications services (ysydye); commerce, food services, material supply and marketing and storage (syye); nonmaterial (other services) (qtffye) (units: 10,000 RMB)

- two kinds of green house gas emissions: SO_2, CO_2 (units: ten thousand tons)

This study is based on the marginal opportunity cost theory for natural resources pricing and the Chinese National Accounting System reform.

3. ELEMENTARY CONTEXTUAL ANALYSIS AT STARTING POINT IN 1992

On the basis of this GIO table, we obtain the synthesis of direct and complete consumption coefficient matrices, respectively. The synthesis includes four parts of a direct consumption coefficient table: natural resources direct input in use coefficients, energy products direct consumption coefficients, non-energy products direct consumption coefficients, and pollution direct emission coefficients. [6]

From the direct consumption coefficient matrix, we can see that, in 1992, about 600 tons of coal were used directly per million RMB of output in coal mining and processing, about 243 tons of petroleum and natural gas were used directly per output (million RMB) in petroleum and natural gas sector, and about 0.13 ton of coal and 0.012 ton of petroleum and natural gas were used directly per GDP (million RMB).

For polluting emissions, electrical power generation—steam and hot water production and supply—is the top sector for SO_2 and CO_2 source. Without considering abatement in 1992, this sector emitted directly about 141 tons of SO_2 and 2,378 tons of CO_2 per unit of output value (million RMB), which is over 97% of all SO_2 and over 93% of all CO_2 emitted. The second and third highest emitters of greenhouse gases are the petroleum processing sector and the coking, gas and coal-related products sectors, which emitted about 106 tons and 41 tons CO_2 and 0.23 ton and 2.44 ton SO_2 per unit of output value (million RMB), respectively. Meanwhile, 0.03 ton SO_2 and 0.55 ton CO_2 were emitted directly per unit of GDP (million RMB) in 1992.

From the consumption coefficient matrix, we can see that coal occupies an extremely high share in the structure of energy consumption in power generation: nearly 97% in 1992 (see figure 1).

[INSERT FIGURE 1 ABOUT HERE]

From this we can already conclude primarily that there are serious problems existing in the efficiency – in particular ecological efficiency - of Chinese energy production and the structure of power generation. There is a heavy waste of coal resources which result from the lower coefficient of recovery of coal which is about 32.6% lower than the average level in the world (see Lei, 1999). The proportion of coal power in total power generation is very high (over 90%), which results in the power generation sector (which includes the steam and hot water production and supply) being the top generator of SO_2 and CO_2 emissions in China.

4. BASIC MODELS

4.1 Basic GIO Models

On the basis of table 1, the following two kinds of input-output models are the basis of my analysis: a physical and a value model.

4.1.1 Physical Models

$$G^{e}\underline{\alpha}X^{e} + G^{p1}X^{p1} + G^{p2}X^{p2} + G^{p3}X^{p3} + G^{w}\underline{\beta}X^{w} + Y^{e} = X^{e}$$

$$A^{e1}\underline{\alpha}X^{e1} + A^{p11}X^{p1} + A^{p12}X^{p2} + A^{p13}X^{p3} + A^{w1}\underline{\beta}X^{w1} + Y^{p1} = X^{p1}$$

$$A^{e2}\underline{\alpha}X^{e2} + A^{p21}X^{p1} + A^{p22}X^{p2} + A^{p23}X^{p3} + A^{w2}\underline{\beta}X^{w2} + Y^{p2} = X^{p2}$$

$$A^{e3}\underline{\alpha}X^{e3} + A^{p31}X^{p1} + A^{p32}X^{p2} + A^{p33}X^{p3} + A^{w3}\underline{\beta}X^{w3} + Y^{p3} = X^{p3}$$

$$F^{e}\underline{\alpha}X^{e} + F^{p1}X^{p1} + F^{p2}X^{p2} + F^{p3}X^{p3} + F^{w}\underline{\beta}X^{w} + Y^{w} = X^{w}$$

where: $G^{*} = (g^{*}_{ij})^{T}_{(L\times S)}$

$A^{*} = (a^{*}_{ij})^{T}_{(N\times S)}$

$F^{*} = (f^{*}_{ij})^{T}_{(M\times S)}$

$X^{e} = \underline{\alpha}^{-1} Z^{e}$

$X^{w} = \underline{\beta}^{-1} Z^{w}$

$Z^{p} = X^{p}$

$Z^{*} = (Z^{*}_{1}, Z^{*}_{2}, \ldots, Z^{*}_{k})^{T}$

$Y^{*} = (Y^{*}_{1}, Y^{*}_{2}, \ldots, Y^{*}_{k})^{T}$

$X^{*} = (X^{*}_{1}, X^{*}_{2}, \ldots, X^{*}_{k})^{T}$

$\underline{\alpha} = \mathrm{diag}(\alpha_{1}, \alpha_{2}, \ldots, \alpha_{L})$

$\underline{\beta} = \mathrm{diag}(\beta_{1}, \beta_{2}, \ldots, \beta_{M})$

$g^{e}_{ij} = U^{e}_{ij} / Z^{e}_{j}$

$g^{p}_{ij} = U^{p}_{ij} / Z^{p}_{j}$

$g^{w}_{ij} = U^{w}_{ij} / Z^{w}_{j}$

$a^{e}_{ij} = q^{e}_{ij} / Z^{e}_{j}$

$a^{p}_{ij} = q^{p}_{ij} / Z^{p}_{j}$

$a^{w}_{ij} = q^{w}_{ij} / Z^{w}_{j}$

$f^{e}_{ij} = e^{e}_{ij} / Z^{e}_{j}$

$f^{p}_{ij} = e^{p}_{ij} / Z^{p}_{j}$

$f^{w}_{ij} = e^{w}_{ij} / Z^{w}_{j}$

$\alpha_{i} = Z^{e}_{i} / X^{e}_{i}$

$\beta_{i} = Z^{w}_{i} / X^{w}_{i}$

$S=L+N+M$

for * as e, p**(**= primary energy products, secondary energy products, and other products), w, k = L, N, M, and T indicates transferred matrix

4.1.2 Value Models

$$P^e = G^e P^e + A^{e1} P^{p1} + A^{e2} P^{p2} + A^{e3} P^{p3} + F^e P^w + B^e$$

$$P^{p1} = G^{p1} P^e + A^{p11} P^{p1} + A^{p12} P^{p2} + A^{p13} P^{p3} + F^{p1} P^w + B^{p1}$$

$$P^{p2} = G^{p2} P^e + A^{p21} P^{p1} + A^{p22} P^{p2} + A^{p23} P^{p3} + F^{p2} P^w + B^{p2}$$

$$P^{p3} = G^{p3} P^e + A^{p31} P^{p1} + A^{p32} P^{p2} + A^{p33} P^{p3} + F^{p3} P^w + B^{p3}$$

$$P^w = G^w P^e + A^{w1} P^{p1} + A^{w2} P^{p3} + A^{w3} P^{p3} + F^w P^w + B^w$$

where: $P^* = (p^*_1, p^*_2, \ldots, p^*_k)^T$

$B^* = (b^*_1, b^*_2, \ldots, b^*_k)^T$

$b^e_j = N^e_j / Z^e_j$

$b^p_j = N^p_j / Z^p_j = N^p_j / X^p_j$

$b^w_j = N^w_j / Z^w_j$

P^e_i are the resource tax imposed for using per unit resource *i* (here referring to the recovery cost of per unit resource *i*)

P^p_i is the price of product *i*

P^w_i is the emission cost imposed for emitting pollutant *i* (here referring to the cost consumed by managing per unit pollutant *i*)

for * as e, p**(**= primary energy products, secondary energy products, and other products), w, and k = L, N, M

Balance Models

$$X^{p1} = Z^{p1}$$

$$X^{p2} = Z^{p2}$$

$$X^{p3} = Z^{p3}$$

4.2 Forecast for GDP and Final Demand of Non-energy Sectors

GDP is forecast as follows:

$$GDP_t = GDP_0 (1 + r_{GDP})^t \quad t=0,1,2,\ldots\ldots$$

where: 0 is the base year

r_{GDP} is the annual GDP growth rate

t is the year

I forecast final demand (FD) of non-energy sectors as following,

$$FD_t^{(*)} = \alpha_{(*)} * GDP_t$$

where: $\alpha_{(*)}$ is the proportion of each non-energy sector's final demand against the GDP in 1992

(*) subscript above indicates here thirteen non-energy production sectors: farming, forestry, animal husbandry, fishery and water conservancy; food, beverages, and tobacco; textiles; paper-making and paper products; chemicals and allied products; building materials and other; smelting and pressing of metals; machine building, electric and electronic equipment; other manufacturing; construction; transportation, post and telecommunications services; commerce, food services, material supply and marketing and storage; nonmaterial (other services)

4.3 Forecast for Energy Final Demand

Final demand for energy is forecast using the elasticity forecasting method:

$$FD_t^{(*)} = FD_{1992}^{(*)} (1 + \varepsilon_{(*)} * r_{GDP})^t \quad t=0,1,2,\ldots..$$

where: $\varepsilon_{(*)}$ is elasticity of final demand for each energy product against GDP

(*) subscript above indicates here coal, petroleum and natural gas, power, petroleum refinery products, and coke.

The elasticity of the final demand for each energy product is estimated based on the data from International Energy Agency (IEA, 1996-2002) Statistics Year Book.

- Elasticity of Coal to GDP

COATFCOL = 0.23271356*GDPL + 8.5485887 + [AR(1)=-0.051307486] [7]

(3.61) (10.52) (–0.47)

where: COATFCOL is final demand for coal

GDPL is GDP

Elasticity of Coal = 0.23271356 [8]

- Elasticity of Petroleum and Natural Gas to GDP

PETROGASTFCOL = 1.4155902*GDPL - 10.608795 + [AR(1)=0.38531649]

(6.9) (–4.08) (1.4)

where: PETROGASTFCOL is Final Demand of Petroleum and Natural Gas

Elasticity of Petroleum and Natural Gas = 1.4155902 [9]

- Elasticity of Electricity to GDP

ELETFCOL = 1.068432*GDPL - 4.4455671 + [AR(1)=0.093879952]

(14.7) (–4.84) (1.52)

where: PETROGASTFCOL is final demand for electricity

Elasticity of Electricity=1.068432

- Elasticity of Petroleum Refinery Products to GDP

TPRTFCOL = 0.63327857*GDPL + 1.6259491 + [AR(1)=0.25973122]

(8.15) (1.65) (3.72)

where: PETROGASTFCOL is final demand for petroleum refinery products

Elasticity of Petroleum Refinery Products=0.63327857

- Elasticity of Coke to GDP

Elasticity of Coke=0.23271356 [10]

4.4 Forecast for Total Energy Consumption

In light of the above final demand (non-energy & energy) forecast and the complete consumption coefficient, we can forecast total energy consumption as follows:

$$\begin{pmatrix} X_t^N \\ X_t^{FN} \end{pmatrix} = (I - A)^{-1} \begin{pmatrix} Y_t^N \\ Y_t^{FN} \end{pmatrix}$$

where: A is the direct consumption coefficient matrix (1992)

X_t^N, Y_t^N are total consumption and final demand of energy products in year t respectively

X_t^{FN}, Y_t^{FN} are total consumption and final demand of non-energy products in year t respectively

4.5 Forecast for Natural Resources Used

In this paper, only coal resources will be considered. Hence, the forecast of coal resource used directly can be obtained as follows:

$$D_t = S_t / \sigma$$

$$S_t = (1 + \lambda * r_{GDP})^t S_0$$

where: D_t, S_t are the amount of coal resource used and of coal product produced respectively

λ is the production elasticity of coal

σ is the coefficient of recovery

S_0 is the total coal production of China in base year

4.6 Forecast for SO_2 and CO_2 Emissions

To estimate Chinese SO_2 and CO_2 emission in the future (2020), we considered only SO_2 emission from coal burning and CO_2 emission from primary energy (fossil fuels: coal, petroleum, and natural gas).

Considering that 84% of coal is used directly for burning and that the average sulfur content of coal is 0.0205712 in China today (see Lei, 1999 a), we estimated the SO_2 emission as follows:

The amount of SO_2 emission (in tons) =1.6*0.0205712*0.84*total coal consumption (in tons).

The amount of CO_2 emission (in tons) =the amount of CO_2 emission with coal used + the amount of CO_2 emission with petroleum and natural gas used

=0.651*total coal consumption (in tons of coal equivalent (TCE)

+((0.543+0.404)/2)* total petroleum & natural gas

consumption (in TCE)

The parameters 0.651, 0.543 and 0.404 are total CO_2 emission per unit coal, petroleum, and natural gas consumption (ton/TCE), respectively (see Zhang and Folmer, 1997).

5. ASSUMPTION AND DATA

To make this analysis, I chose six scenario assumptions in comparison to a basic reference scenario, as follows.

5.1 The Basic Reference Scenario

According to the outline of Chinese 9th and 10th Five

Year Plan for National Economic and Social Development and the Long-Term Targets to 2015, adopted by the Chinese National People's Congress in March 1996, we also assumed the Chinese annual GDP growth rate to be 8% before 2010, and 7% from 2010 to 2020, with 2003 as the base year. However unrealistic - initially - as a reference comparison point this may be, in this basic scenario the structure of technological economic relationships (direct consumption coefficient matrix) would remain unchanged from 1992 to 2020; so would the final demand structure of non-energy sectors; so would the elasticity between energy final demand and GDP, as that of coal and coke, petroleum and natural gas, electrical power, petroleum refinery products; and so would the coal coefficient of recovery of China remain at 32.6%, unchanged before 2020. This basic reference scenario then enables us to estimate the effects on emissions of different changes.

5.2 Scenario I: Improved Coal Recovery.

For this scenario, all the above assumptions are kept – except one: the coal coefficient of recovery of China would be changed from 32.6%, in 1992, to 50% in 2020. We take into consideration the 1996 Chinese Coal Law, under which over half of the villages' and townships' coal mines should semi-mechanize during that period.

5.3 Scenario II: Change in Final Demand Structure.

In this scenario, all assumptions are also the same as for the basic reference scenario - except one concerning the final demand structure of non-energy sectors. By 2020, the proportion of final demand for chemicals and allied products against GDP will decrease 10% from the 1992 level, but the proportion of final demand for nonmaterial production sectors against GDP will increase 10% from the 1992 level.

5.4 Scenario III: Decreased Coal, Increased Hydro and Nuclear Sources of Power.

For this scenario, all assumptions are the same as for the basic reference scenario - except the energy consumption structure in power generation is changed. The proportion of coal consumption against total energy consumption in power generation would decrease from the 1992 level of 96.58% to 86.58%, due to hydroelectric power, with the Three Gorge Dam completed in 2009, and new nuclear power generation plants would be built.

5.5 Scenario IV: The Impact of Putting Sulfur Scrubbers.

In this scenario, all the basic reference scenario assumptions are kept - except the sulfur content of coal in power generation decrease 10%, by putting sulfur scrubbers on all coal fired power plants.

5.6 Scenario V: Increased Energy Conversion Efficiency.

In this scenario, all assumptions are the same as for the basic reference scenario - except the 10% decrease of energy input coefficients in energy sectors, which corresponds to the effect of an increase in energy production and conversion efficiency. [11]

5.7 Scenario VI: Increased Energy Conservation Efficiency.

In this scenario, all assumptions are the same as for the basic reference scenario - except for a 10% decrease in energy input coefficients in both non-energy sectors and energy final demand, which corresponds to the effect of the increase in final energy consumption efficiency. [12]

All the data used in this study come from *Chinese Statistical Year Book*, Chinese Input-output Table (see State Statistical Bureau of China, 1993-02; 1996), relevant materials on Chinese natural resources and environmental issues,[13] and relevant research reports on pricing and accounting of natural resources, as well as other materials.

6. OUTCOMES

6.1 Base Reference Scenario

- GDP would be about 2.39×10^{14} RMB in 2020,

- In 2020, gross production of coal in China would be about 2267.99 million tons but the total coal resources used in the production process will be about 6957.01 million tons (see figure 2). On the other hand, total coal resources used in the production process per GDP would decrease to about 1303.52 (ton/million RMB) in 2020 from 291.49 (ton/million RMB) of 1992 (77.64% decrease).

[FIGURE 2 ABOUT HERE]

- Until 2020, total energy consumption would be 6570.03 million tons of oil equivalent (TOE) (see figure 3), in which coal would be 4361.65 million TOE, petroleum, and natural gas would be 1143.43 million TOE, power would be 55.66 million TOE, petroleum refinery products would be 554.56 million TOE, coke would be 454.72 million TOE, however total energy consumption per GDP would decrease to about 2.75 (TOE/ten thousand RMB) in 2020 from 3.01 (TOE/ten thousand RMB) of 1992 (8.46% decrease).

[FIGURE 3 ABOUT HERE]

- The structure of total energy consumption per GDP would be changed, with the proportion of coal against total energy consumption dropping from the 1992 level of 0.689 to 0.664 in 2020 (3.6% decrease), petroleum and natural gas rising from 0.161 to 0.174 (8.1% increase), power rising from 0.0077 to 0.0085 (10.39% increase), and petroleum refinery products rising from 0.078 to 0.084 (7.69% increase).

(FIGURE 4 APPROXIMATELY HERE)

- The structure of final consumption of energy would also be changed. The proportion of coal against total energy final consumption dropping from the 1992 level of 0.97 to 0.91 in 2020 (6.2% decrease). The proportion of petroleum and natural gas against total energy final consumption would rise from 0.00026 to 0.0031 (19% increase). (see Figure 4)

- Total SO_2 and CO_2 emissions would increase from the 1992 level of 30.49 million tons and 600.17 million tons to 241.18 million tons, 4829.93 million tons in 2020, respectively (see figure 5).

[FIGURE 5 ABOUT HERE]

However, SO2 and CO2 emissions per GDP would decrease from the 1992 level of 11.45 (tons/million RMB) and 225.26 (tons/million RMB) to 10.11(tons/million RMB) and 202.37 (tons/ million RMB) in 2020 (11.7% and 10.16%) decreases respectively (see figure 6).

[FIGURE 6 ABOUT HERE]

In order to summarize and compare the main effects of the 5 different scenarios, we have focused on coal production and coal use reduction, and final green house gas emissions reductions in Table 2:

Table 2: Green House Gas, Coal Resource and Coal Energy Use Reduction under 6 Scenarios

	Base Reference	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
Assumption	*(see text)*	*Coal Recovery Efficiency up to 50%*	*Final Demand for Chemicals in GDP – 10%*	*Coal Energy Consumption in Power Generation down to 86.5% (-10%)*	*Sulfur Content of Coal in Coal Fired Power Plants -10%*	*+10% Energy Production & Conversion Efficiency*	*+10% in Total Energy Efficiency*
Coal Resource Use/GDP	-77.64%	-34.8%	-	-	-	-	-
Total Energy Consumption/GDP	-8.46%	-	-10.01%	-2.52%	-	-6.06%	-9.84%
Coal Energy Consumption/ Total Energy Consumption	-3.6%	-	-1.03%	-1.26%	-	-0.05%	+0.23%
SO2 / GDP	-11.7%	-	-11.04%	-3.47%	-9.66%	-6.1%	-9.64%
CO2 / GDP	-10.2%	-	-10.93%	-3.16%	-	-6.79%	-9.73%

***Notes*: - is unchanged or uncertain.**

6.2 Scenario I

Total use of coal in the production process would decrease from 6,957.01 million tons to 4,535.97 million tons in 2020 under the assumption that coal coefficient of recovery increases to 50% in 2020, compared to the basic reference scenario. **The depletion (waste in the coal exploitation process) of coal resource under this scenario would be reduced by 51.6%, and total coal resources used in the production process per GDP would decrease 34.8%.**

6.3 Scenario II

In this scenario, total energy consumption per GDP would decrease 10.01% in 2020, SO_2 and CO_2 emissions per GDP decreasing 11.04% and 10.93% in

2020, respectively, compared with the basic scenario, with the 1992 final demand structure of non-energy sectors unchanged. And the proportion of coal against total energy consumption would decrease 1.03% in 2020.

6.4 Scenario III

For this scenario, total energy consumption per GDP would decrease 2.52%，SO_2 and CO_2 emissions per GDP would decrease by 3.47% and 3.16% in 2020, respectively, and the proportion of coal against total energy consumption would decrease 1.26% in 2020, compared with the basic reference scenario, in which the 1992 level of energy consumption structure in power generation would remain unchanged in 2020.

6.5 Scenario IV

In this scenario, the impact of putting sulfur scrubbers on all coal fired power plants would be striking. SO_2 emissions per GDP will decrease by 9.66% in 2020, compared with the basic reference scenario.

6.6 Scenario V

In this scenario, total energy consumption per GDP will decrease by 6.06% in 2020, SO_2 and CO_2 emissions per GDP will decrease by 6.1% and 6.79% in 2020, respectively, and the proportion of coal against total energy consumption would decrease 0.05% in 2020, compared with the basic reference scenario.

6.7 Scenario VI

In this scenario, total energy consumption per GDP in China will decrease by 9.84% in 2020, SO_2 and CO_2 emissions per GDP will decrease 9.64% and 9.73% in 2020, respectively, and the proportion of coal against total energy consumption would increase 0.23% in 2020, compared to the basic reference scenario.

7. CONCLUSIONS

From the above scenario analysis, we can draw the following general and basic conclusions about China's energy and environmental situation for the period 1992–2020:

- The low coal coefficient of recovery in China is one key issue that results in low efficiency and high waste in Chinese current subsoil energy resources.

- To protect Chinese natural resources it is necessary to promote the efficient recovery of subsoil energy resources such as coal, and reduce the waste in the resources exploitation process.

- Coal, especially coal used in power generation, is the main cause of SO_2 and CO_2 emissions in China today, and this GIO analysis indicates that this is likely to remain so in the future unless may conditions are changed.

According to our scenario estimates, the following policy options would have most effects on green house gas emissions in the next decade and a half.

- Changing the energy consumption structure in power generation, by raising the efficiency of energy transformation, increasing hydroelectric power and nuclear power generation, and decreasing fossil-fuel generated power, is an ecologically effective way of reducing SO_2 and CO_2 emissions.

Changing the final demand structure, by decreasing the proportion of chemicals and allied products and increasing the proportion of the other industrial products and services in final demand, is the most efficient means to reduce SO_2 and CO_2 emissions.

Putting sulfur scrubbers on all coal fired power plants is the most efficient means to reduce SO_2.

Enhancing energy efficiency, energy production and conversion efficiency, and final energy consumption efficiency—especially the last—is the most efficient means to reduce CO_2 emissions, and is almost the same most efficient means as putting sulfur scrubbers on all coal fired power plants to reduce SO_2 emissions. [14]

The above policy option scenario and their impact have been estimated from the point of view of green house gas emission reductions in China. Some of these policy options may be complementary or substitute. Neither have various policy mixes been examined here. Nor have the relative investment costs of each policy option as yet been evaluated. More specific technological changes have not been considered. However, the centrality of coal and inefficiencies in power resources recovery, production, conversion related to power in China is clearly unavoidable – as are the green house gas emissions which accompany thermal coal based energy.

NOTES

1. This is the first time this is done for china.

2. Marginal opportunity cost was only put forward as a new concept in Pearce and Markandya's work (1989), methods of the values estimated of the three marginal costs in MOC was not given there (see Pearce and Markandya, 1989). For this, please see Lei (1999a, 2000a) in which methods of the three marginal costs estimated

was discussed in detail.

3. In the work of my green input-output accounting to China, for simplify, replacement cost method be generally used in which marginal natural resource recovery cost be used to estimated marginal user cost and marginal pollutant abatement cost be used to estimated marginal environmental cost (see Lei, 2000a).
4. In this paper we will focus only on CO_2 and SO_2, the two main green house gas emissions related to fossil fuels.
5. All the above are included, but the natural-resources-recovery and pollution-abatement sectors of table 1 are not considered in this paper. For complete GIO table compilation and application analysis, see Lei (2000b, 2002).
6. We are assuming for the purpose of this scenario analysis fixed input coefficients and constant production process technology (unless overwise specified in the description of each scenario).
7. Statistics for these econometric equations are given in appendix 1.
8. Although the adjusted R-squared in our above estimate is low – see appendix 1 -, we accepted this estimated elasticity by comparison with other countries and other estimations in China.
9. This elasticity is actually the elasticity of natural gas against GDP since the final demand of petroleum was zero in 1992.
10. With limited relevant data, we assume the elasticity of coke final demand to GDP is as same as the elasticity of coal, i.e. 0.23271356.
11. Current energy production and conversion efficiency of China is lower by more than 10% than that of developed countries. See State Statistical Bureau of China (1993–02), IEA (1996–02) and Lei, M. (2004).
12. Final energy consumption efficiency of China is also lower by about 10% than that in developed countries. See State Statistical Bureau of China (1993–02), IEA (1996–02) and Lei, M. (2004).
13. Such as papers, reports, government documents, etc..
14. In this paper, we have not considered the compared economic efficiency of any option above compared to the others.

Table 1: Green Input-output Table of Integrated Energy-Natural Resources-Energy- Economy-Environment

Output / Input	Resource recovery sector	Primary energy sector	Secondary energy sector	Other products sector	Pollution-abatement sector	Final products	Total output
Resource used	u^{e}_{ij}	u^{p1}_{ij}	u^{p2}_{ij}	u^{p3}_{ij}	u^{w}_{ij}	Y^{e}_{i}	X^{e}_{i}
Primary energy products	q^{e1}_{ij}	q^{p11}_{ij}	q^{p12}_{ij}	q^{p13}_{ij}	q^{w1}_{ij}	Y^{p1}_{i}	X^{p1}_{i}
Second energy products	q^{e2}_{ij}	q^{p21}_{ij}	q^{p22}_{ij}	q^{p23}_{ij}	q^{w2}_{ij}	Y^{p2}_{i}	X^{p2}_{i}
Other products.	q^{e3}_{ij}	q^{p31}_{ij}	q^{p32}_{ij}	q^{p23}_{ij}	q^{w3}_{ij}	Y^{p3}_{i}	X^{p3}_{i}
Pollution emitted	e^{e}_{ij}	e^{p1}_{ij}	e^{p2}_{ij}	e^{p3}_{ij}	e^{w}_{ij}	Y^{w}_{i}	X^{w}_{i}
Value-added	N^{e}_{j}	N^{p1}_{j}	N^{p2}_{j}	N^{p3}_{j}	N^{w}_{j}		
Total input	Z^{e}_{j}	Z^{p1}_{j}	Z^{p2}_{j}	Z^{p3}_{j}	Z^{w}_{j}		

where: u^{e}_{ij} is the amount of natural resource *i* consumed by natural resource recovery sector *j* (units: ton/stere)

q^{ek}_{ij} is the amount of products of sector *i*, industry *k* (*k* = primary energy industry, secondary energy industry, and other industry) consumed by natural resource recovery sector *j* (units: RMB)

e^{e}_{ij} is the amount of pollutant *i* emitted by natural resource recovery sectors *j* (units: ton/stere)

N^{e}_{j} is value-added of natural resource recovery sector *j* (units: RMB)

Y^{e}_{i} is the amount of natural resource *i* consumed in final consumption (units: ton/stere)

X^{e}_{i} is total amount of natural resource *i* consumed (units: ton/stere)

Z^{e}_{i} is total amount of natural resource *i* recovered (units: ton/stere)

u^{pk}_{ij} is the amount of natural resource *i* consumed by sector *j*, industry *k* (*k* primary energy industry, secondary energy industry, and other industry) (units: ton/stere)

q^{pkl}_{ij} is the amount of products of sector *i*, industry *k* (*k*= primary energy industry, secondary energy industry and other industry) consumed by sector *j*, industry *k* (*k* = primary energy industry, secondary, energy industry and other industry) (units: RMB)

e^{pk}_{ij} is the amount of pollutant *i* emitted by sector *j*, industry *k* (*k* = primary energy industry, secondary energy industry, and other industry) (units: ton/stere)

N^{pk}_{i} is value-added of sector *i*, industry *k* (*k* = primary energy industry, secondary energy industry, and other industry) (units: RMB)

Y^{pk}_{i} is final product of sector *i*, industry *k* (*k* = primary energy industry, secondary energy industry, and other industry) (units: RMB)

X^{pk}_{i} is total output of sector *i*, industry *k* (*k* = primary energy industry, secondary energy industry, and other industry) (units: RMB)

Z^{pk}_{i} is total input of sector *i*, industry *k* (*k* = primary energy industry, secondary energy industry, and other industry), equal to X^{pk}_{i} in values (units: RMB)

u^{w}_{ij} is the amount of natural resource *i* consumed by pollution-abatement sector *j* (units: ton/stere)

q^{wk}_{ij} is the amount of products of sector *i*, industry *k* (*k* = primary energy industry, secondary energy industry, and other industry) consumed by pollution-abatement sector *j* (units: RMB)

e^{w}_{ij} is the amount of pollutant *i* emitted by pollution-abatement sector *j* (units: ton/stere)

N^{w}_{j} is value-added of pollution abatement sectors *j* (units: RMB)

Y^{w}_{i} is the amount of pollutant *i* emitted in the final consumption (units: ton/stere)

X^{w}_{i} is total pollutant *i* emitted (units: ton/stere)

Z^{w}_{i} is total amount of pollutant *i* abated (units: ton/stere)

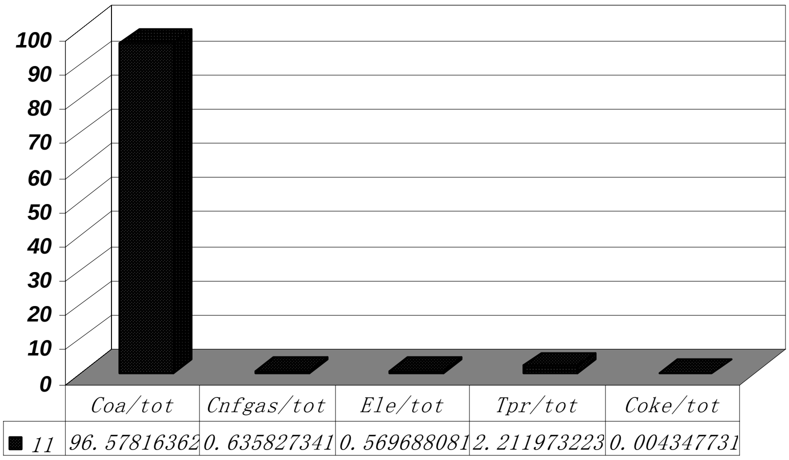

Figure 1. Structure of energy consumption in power generation (%)

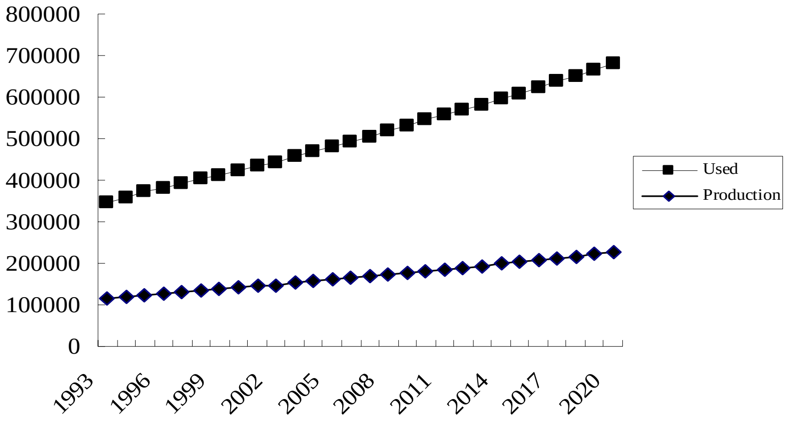

Figure 2. Coal production and coal resources used (ten thousand tons)

(Base reference scenario)

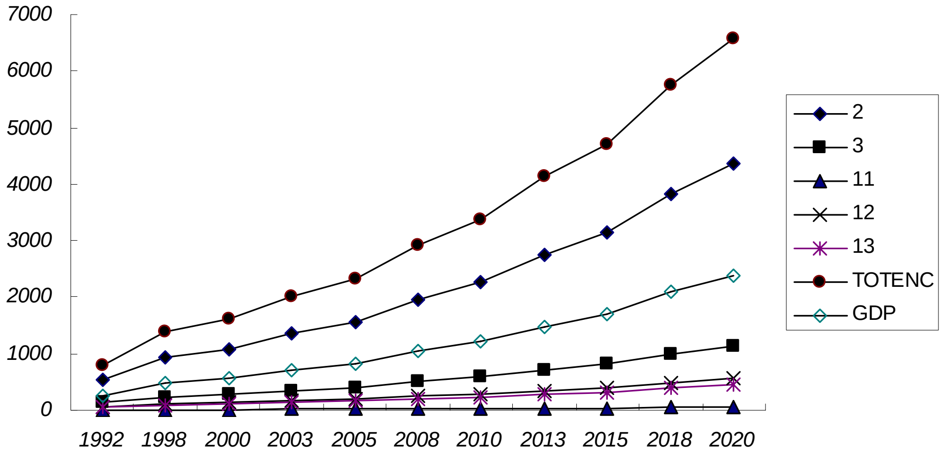

Figure 3: Total energy consumption (million tons of TOE)

(Base reference scenario)

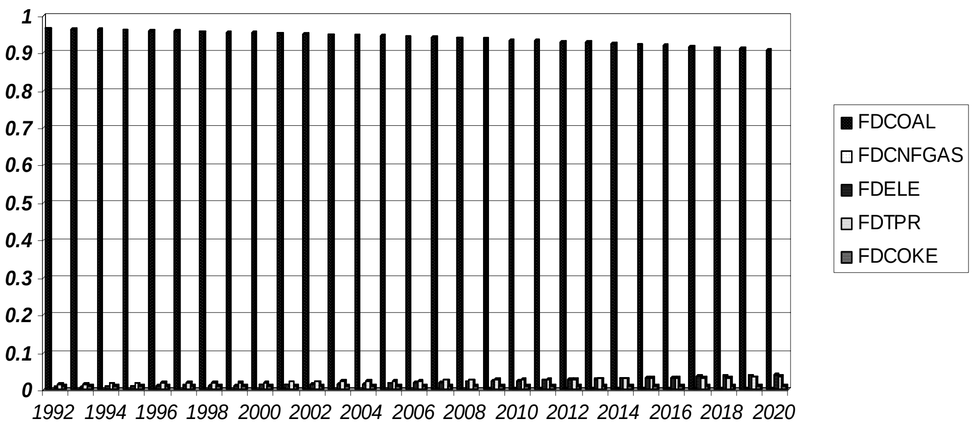

Figure 4: Structure of total energy consumption

(Base reference scenario)

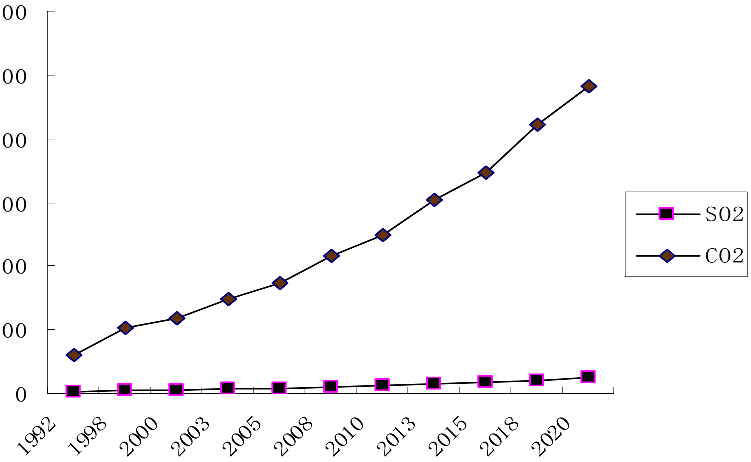

Figure 5. SO_2/CO_2 emissions (hundred thousand tons) (Base reference scenario)

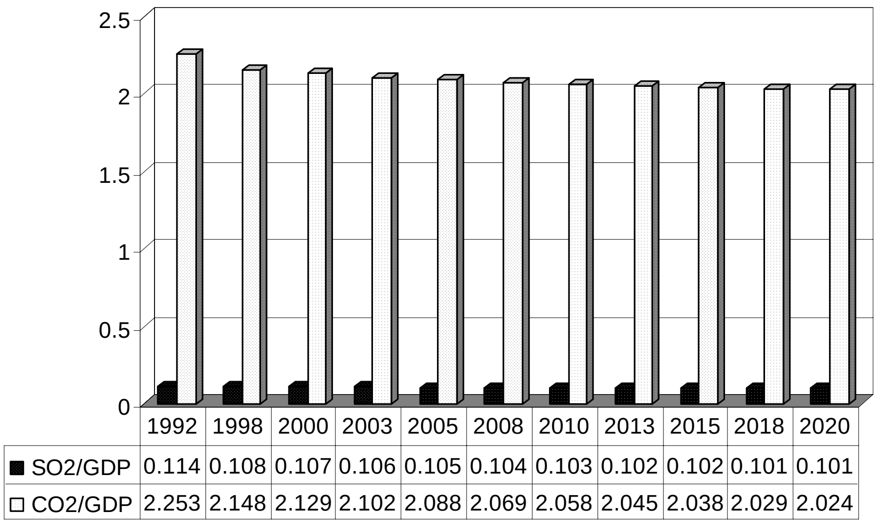

Figure 6. Per GDP SO_2/CO_2 emissions (tons/ten thousand RMB)
(Base reference scenario)

Appendix 1: Elasticity Estimate Equation Statistics

Coal to GDP elasticity equation statistics

R-squared	0.542317	Mean dependent var	11.46673
Adjusted R-squared	0.466037	S.D. dependent var	0.137823
S.E. of regression	0.100711	Akaike info criterion	-4.414140
Sum squared resid	0.121713	Schwarz criterion	-4.272530
Log likelihood	14.82198	F-statistic	7.109518
Durbin-Watson stat	0.274951	Prob(F-statistic)	0.009192

Petroleum and Natural Gas to GDP elasticity equation statistics

R-squared	0.918297	Mean dependent var	7.232200
Adjusted R-squared	0.903442	S.D. dependent var	0.575872

S.E. of regression	0.178946	Akaike info criterion	-3.253937
Sum squared resid	0.352237	Schwarz criterion	-3.116996
Log likelihood	5.912421	F-statistic	61.81674
Durbin-Watson stat	2.123511	Prob(F-statistic)	0.000001

Electricity to GD elasticity equation statistics

R-squared	0.962352	Mean dependent var	8.980132
Adjusted R-squared	0.956078	S.D. dependent var	0.435272
S.E. of regression	0.091223	Akaike info criterion	-4.612045
Sum squared resid	0.099859	Schwarz criterion	-4.470435
Log likelihood	16.30626	F-statistic	153.3726
Durbin-Watson stat	0.629007	Prob(F-statistic)	0.000000

Petroleum Refinery Products to GDP elasticity equation statistics

R-squared	0.912684	Mean dependent var	9.605952
Adjusted R-squared	0.898131	S.D. dependent var	0.238884
S.E. of regression	0.076244	Akaike info criterion	-4.970770
Sum squared resid	0.069758	Schwarz criterion	-4.829160
Log likelihood	18.99670	F-statistic	62.71585
Durbin-Watson stat	1.283940	Prob(F-statistic)	0.000000

REFERENCES

Balistreri, E. J. & Rutherford, T. F.. (2000). *Dynamic General Equilibrium Analysis at the State Level: Assessing the Economic Implications of the Kyoto Protocol* (Colorado, University of Colorado).

IEA (1996–02). *Energy Statistics and Balance of Non-OECD Countries* (Paris).

Jiang, K.. (2002). *Long-term emission scenarios for China, Proceedings of Climate Change Policy Assessment* (Beijing, Energy Research Institute of China).

Lei, M.. (1995). *Study on integrated accounting for natural resources and the economy, Postdocs Research Working Report* (Peking University, China). (In Chinese.)

Lei, M.. (1996a). 'Input-output accounting for natural resources & economy: Tabling, modeling and application analysis', *Economic Science*, 1, pp. 42–51. (In Chinese.)

Lei, M.. (1996b) . 'Accounting of resources--economic input and output—further research on the basis of stock accounting consideration', *Economic Science*, 6, pp. 46–54. (In Chinese.)

Lei, M.. (1997). 'Study on integrated accounting for natural resources and economy', *Journal of Systems Science & Systems Engineering*, 6(3), pp. 257–62.

Lei, M. (1999a) *Green accounting for sustainable development: Integrated accounting of natural resources-economy-environment* (Beijing, China's Geography Press). (In Chinese.)

Lei, M.. (1999b) . 'Input-output accounting for natural resources-economy-environment. Proceedings of the 14th World Congress of the International Federation of Automatic Control (IFAC)', 50, pp. 115–20. *Oxford: Elsevier Science.*

Lei, M.. (2000a). *Green Input-Output Accounting--Theoretical & Application* (Beijing, Peking University Press). (In Chinese.)

Lei, M.. (2000b). *Integrated Input-output Accounting for Natural Resources-Energy-Economy- Environment*, paper presented at the 13th International Conference of Input-Output Techniques, Aug.21-25, 2000, Macerata, Italy.

Lei, M.. (2001) . 'Trial estimation of 95'CSEEA and 95'Green GDP of China. Bulletin of the International Statistical Institute', 53(1), pp. 46–54, paper presented at the *53rd Session of the ISI*, August 22–29, 2001, Seoul, Korea.

Lei, M. (2002) *Study on China's sustainable development: Integrated input-output analysis and green charges for China*, paper presented at the 14th International Conference on Input-Output Techniques, Oct. 10–16, 2002, Montreal, Canada.

Lei, M.. (2003). *Green input-output accounting for natural resources-energy-economy– environment. Bulletin of the International Statistical Institute*, 54(1), pp. 718–19, paper presented at the 54th Session of the ISI, August 13–20, 2003, Berlin, Germany.

Lei, M.. (2004). 'Green GDP and Sustainable Energy Sources', *Construction Science and Technology*, 5, pp. 18-19. (In Chinese.)

Leontief, W. et al.. (1972). ' Air pollution and the economic structure: empirical outcomes of input-output computation, in Bródy, A. & Carter, A. P. (eds)', *Input-Output Techniques*, pp. 9–30 (Amsterdam/London, North-Holland).

Lin, X. & Polenske, K. R.. (1995). 'Input-output anatomy of China's energy use changes in the 1980s', *Economy Systems Research*, 7(1), pp. 67–84.

Pearce, D. W. & Markandya, A.. (1989). *Marginal opportunity cost as a planning concept in natural resource management, in: G. Schrammand and J. J. Warford (eds), Environmental Management and Economic Development* (Maryland, Johns Hopkins University Press).

State Statistical Bureau of China. (1993–02). *Statistics Year Book of China* (1990s) (Beijing, Chinese Statistics Press). (In Chinese.)

State Statistical Bureau of China. (1996). Chinese Input-Output Table (1992 Value) (Beijing, Chinese Statistics Press). (In Chinese.)

United Nations et al.. (1993). Integrated Environmental and Economic Accounting (Interim Version), Studies in Methods: Handbook of National Accounting, Series F, No. 61 (New York).

United Nations et al.. (2000). Integrated Environmental and Economic Accounting, an Operational Manual: Handbook of National Accounting Series F, No. 78 (New York).

United Nations et al.. (2003). Integrated Environmental and Economic Accounting 2003: Handbook of National Accounting, final draft (New York).

Xu, H.Q., et al.. (2002). Globe climate change: Challenge to China. Proceedings of Climate Change Policy Assessment (Beijing, Energy Research Institute of China). (In Chinese.)

Zhang, Z. X. & Folmer, H.. (1997). 'The Chinese energy system: Implication for future carbon dioxide emissions in China'. *Journal of Energy and Development*, 21(1), pp. 1–44.

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