INPUT-OUTPUT ASSESSMENT OF ENERGY CONSUMPTION AND CARBON DIOXIDE EMISSION IN ASIA

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ABSTRACT; Input-output model was applied to analyze the direct and indirect energy consumptions as well as the corresponding carbon dioxide emissions in the Asia-Pacific region including nine Asian countries and the USA for the year 1985. The analysis was made by combining the Asian International Input-Output Table (1985) of the Institute of Developing Economies with energy statistics available for the countries. The results of the model application were compared among different inter industry sectors of a country, and between inter industry sectors of different countries. The results reveal that almost all the Chinese inter industry sectors have very high energy consumption intensities and carbon dioxide emission intensities per unit monetary production, in sharp contrast to those of other countries. It is also shown that Japan and Singapore substantially rely upon the energy consumption and carbon dioxide embodied in the goods and services imported from other countries.

KEY WORDS; Input-output model, energy analysis, carbon dioxide emission, trade and environment, global interdependence

1. Introduction

Recently, there is a significant growth of energy demand in response to industrialization, urbanization, and societal affluence in Asia, especially in south-east and east Asian countries. The principal source of energy use in this region is fossil fuel, where coal has the largest share. Thus, the intensity of carbon dioxide emission to primary energy consumption of this region is considerably high ; 0.83 T-C/TOE.

The region has diversified economies and development policies resulting in a large difference among countries in sector wise energy consumption and the corresponding carbon dioxide emission in an unit demand of goods and services. By and large, adoption of suitable techno-economic options on both national and regional levels are needed in order to achieve economic growth while restraining the increase of energy demand in this region. Here, the input-output model originally developed by Leontief provides an important and useful tool of analysis for assessing and determining suitable techno-economic policies for the region.

The model can account the total energy induced by the demand of goods and services in an economy, making distinction between direct and indirect consumption demand for energy. Gay and Proops [1] examined the production of carbon dioxide by the UK economy in 1984 using this model and explained the possibility of other applications of this model. The conceptual basis of the methodology was further developed by using the idea of 'embodied energy' [2]. Thus, the model can account for the input-output balance of energy and the corresponding carbon dioxide embodied in the goods and services transacted between inter industry sectors in the same and/or different countries.

In this study, the model is applied to the Asia-Pacific region comprising nine Asian countries (Indonesia, Malaysia, Philippines, Singapore, Thailand, China, Taiwan, Korea and Japan) and the USA for the year 1985. The main objectives of the study are as follows:

(i) to account and compare the total (direct plus indirect) energy induced by the demand of goods and services, and corresponding cumulative carbon dioxide emissions by various inter industry sectors in each of the countries under consideration;

(ii) to examine the impact of new thermal energy conversion technology on energy consumption as well as on carbon dioxide emission in China; and

(iii) to analyze the global interdependence of energy consumption and carbon dioxide emission in these countries.

2. Input-Output Modeling for Energy and Environment

The energy conservation conditions using the concept of input-output model [3] can be expressed as

$$\alpha_{ij} X_{ij} = \sum_k \alpha_{ik} Z_{kj} + E_{ij}, \qquad (1)$$

where $\alpha = \{\alpha_{ij}\}$ is the matrix of total amount of energy required to produce a monetary unit's worth of output or " embodied energy intensity" coefficients, where α_{ij} denoting the total (direct plus indirect)

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demand of enerygy type 'i' per unit of total output of sector 'j'; $X = \{X_{ij}\}$ is a diagonal matrix representing the total dollar output of sectors, i.e., X_{ij} is the gross dollar output (i.e., sum of intermediate and final demands) of sector 'j', while all the non-diagonal elements of the matrix being zero; $Z = \{Z_{ij}\}$ is the intermediate input matrix, Z_{ij} being the dollar value of sector i's product consumed by sector 'j'; and $E = \{E_{ij}\}$ is the matrix of total energy output of primary energy sectors,where E_{ij} being the external direct input of energy 'i' to sector 'j'.

In matrix form, eq. (1) can be expressed as

$$\alpha X = \alpha Z + E. \qquad (2\text{- }1)$$

Equation (2- 1) reduces to the following:

$$\alpha X = (I - A) E, \qquad (2\text{- }2)$$

where

$A = Z X^{-1}$ is a matrix of input-output coefficients, representing the industrial structure and technology of a country.

From equations (2) we have,

$$\alpha = E X^{-1} (I - A)^{-1} \qquad (3\text{- }1)$$

$$= E (X - Z)^{-1} \qquad (3\text{- }2)$$

$$= E X^{-1} + E X^{-1} A + E X^{-1} A^2 + \cdots\cdots \qquad (3\text{- }3)$$

or,

$$\alpha = \sigma + \beta \qquad (3\text{- }4)$$

where

$$\sigma = E X^{-1} \qquad (4\text{- }1)$$

$$\beta = (\alpha - \sigma) \qquad (4\text{- }2)$$

$$= A (I - A)^{-1} E X^{-1} \qquad (4\text{- }3)$$

$$= A \alpha. \qquad (4\text{- }4)$$

Here, matrix σ is the intensity of energy consumption by direct consumers, while matrix β being the "total" energy requirements to produce one value unit of goods and services by each sector delivered to final demand, or the total production demand (TPD) energy consumption intensity. Hereinafter, σ and β are respectively referred to as "direct" and "indirect" energy consumption intensities. The values of α and β are equal for all sectors except for primary energy sectors.

The above equations (3) and (4) are applicable to environmental analyses with a minor modification. When matrices α, β and σ are multiplied by the vector of carbon dioxide emission per unit of fuel burnt (ε), we obtain the new corresponding matrices for carbon dioxide emission:

$$(\varepsilon \alpha) = \alpha', \ (\varepsilon \beta) = \beta', (\varepsilon \sigma) = \sigma' \text{ and } \varepsilon E = E'. \qquad (5)$$

Here, α' is the matrix of cumulative carbon dioxide emission coefficients; and σ' and β' respectively, are matrices of "direct" and "indirect" carbon dioxide emission coefficients pertinent to the consumption of fossil fuel based energy.

3. Assessment Procedure

Firstly, data should be prepared in order to accomplish the model calculation described above:

3.1. Preparation of the Matrix A

At first, 24 x 24 sectors input-output table of each country was extracted from the Asian International Input-Output Table 1985 [4], and each of them was reduced to 20 x 20 sectors. Thereafter, they were modified as necessary. The 20 x 20 sectors A matrices of the countries were then derived in the normal way, dividing the inter industry flows Z by the respective gross output X.

3.2. Preparation of the Matrix $E X^{-1}$

Data of the primary energy use in an economy measured in physical units are necessary to construct the matrix E. The data should be properly desegregated into energy types, and 4 types of energy sources (i.e., coal, oil, natural gas and electricity) are considered in the present analysis. The consumption amount of these energy types used for energy purposes were obtained for the year 1985 from the published international sources [5, 6]. The energy matrices (4 x 20) were then divided by the respective vector of gross output and were, thus, prepared in the form of (4 x 20) EX^{-1} matrices. Calculations to derive the values of α, β and σ were made accordingly.

3.3. Calculations of Carbon Dioxide Emission

Calculations of carbon dioxide emission was performed according to eq. (5). For comparison purpose, the values of vector (ε) were assumed to be the same as the following average values (in T-C/TOE) for all countries:

(a) Coal: 0.996, (b) Oil: 0.804, (c) Natural Gas: 0.574.

3.4. Estimation of New Technical Coefficients for Energy Sectors of China

The present thermal energy conversion technology in China is assumed to be replaced partially or fully by the modern efficient thermal energy conversion technology in order to achieve a certain level of energy conservation and reduction in carbon dioxide emission. In an input-output table, the column of technical coefficients related to thermal energy conversion (i.e., electricity, steam and hot water) sector describes the existing thermal energy conversion technology. If A_c is the technology that might be replaced by A_n, then new column A_{cn}, reflecting the incorporation of new technology [7] would be

$$A_{cn} = A_c r + A_n (1 - r),$$

where A_n is the column of technical coefficients related to new thermal energy conversion technology, r is the percentage of old energy conversion technology to be used by the thermal power generating sector (i.e., (1 - r) is the percentage of new thermal energy conversion technology that will replace the old energy conversion technology). Then calculation of A_n was done by using the equation

$$A_n = (e_c/e_n) A_c,$$

where e_c and e_n respectively, are the average thermal energy conversion efficiencies of existing and new technologies.

3.5. Trade of Energy and Environmental Loads Embodied in Goods and Services

The matrix of 240 x 240 inter industry sectors of nine Asian countries and the USA from the Asian International Input-Output Table 1985 (IDE, 1992) was reduced to 200 x 200 inter industry sectors where each country having 20 economic sectors. Then values of total energy consumption and corresponding carbon dioxide emission intensities were calculated by using eq. (2).

4. Results and Discussion

4.1. Primary Energy Consumption

Table 1 shows the total and indirect energy consumption intensities, α and β expressed in terms of TOE/1000 US dollar for the ASEAN countries (Indonesia, Malaysia, Singapore, Philippines and Thailand), Korea, Taiwan, China, Japan and the USA.

The energy consumption intensity values differ largely when we compare among sectors in a country and among the same sectors in different countries. In all the countries except Singapore, energy related

Table 1 Energy Consumption Intensities (TOE/1000 US Dollar)

Inter Industry Sectors \ Countries	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	USA
Agriculture	0.05	0.08	0.04	0.4	0.14	0.47	0.16	0.1	0.12	0.48
Livestock	0.09	0.19	0.07	0.08	0.23	0.32	0.29	0.26	0.14	0.42
Forestry & its Products	0.19	0.34	0.26	0.15	0.24	1.07	0.32	0.16	0.15	0.28
Fishery	0.15	0.18	0.3	0.79	0.83	0.49	0.52	0.47	0.38	0.79
Oil & Natural gas	2.68 (1.45)*	3.66 (2.05)*	2.96 (0.14)*	0.64 (0.05)*	4.88 (0.56)*	14.26 (7.05)*	3.16 (0.22)*	3.79 (1.12)*	3.73 (0.3)*	5.21 (2.2)*
Mining (inc. coal)	0.46 (0.2)*	0.95 (0.49)*	2.01 (0.53)*	0.62 (0.51)*	2.22 (0.48)*	40.74 (2.93)*	12.88 (1.2)*	15.21 (0.37)*	10.32 (0.56)*	12.71 (1.98)*
Food,Beverage & Tobacco	0.1	0.3	0.12	0.14	0.26	0.69	0.28	0.22	0.16	0.33
Textile,Leather & their Products	0.23	0.46	0.15	0.08	0.25	1.12	0.37	0.35	0.2	0.39
Pulp,Paper & Printing	0.37	0.22	0.36	0.08	0.38	1.5	0.43	0.37	0.24	0.36
Chemical Products	0.73	0.46	0.31	0.44	0.33	3.86	0.5	0.73	0.45	1.15
Rubber Products	0.26	0.4	0.2	0.36	0.43	1.25	0.35	0.31	0.24	0.47
Non-metallic Mineral Products	0.64	0.66	0.78	0.21	1.22	4.9	1.75	2.35	1.33	1.39
Metal Products	0.57	0.55	1.59	0.09	0.69	4.88	0.73	0.72	0.41	0.77
Machinery	0.12	0.24	0.44	0.04	0.29	2.01	0.37	0.33	0.19	0.24
Transport Equipments	0.25	0.07	0.36	0.07	0.26	1.96	0.44	0.31	0.2	0.26
Other Manufacturing	0.14	0.41	0.42	0.13	0.17	1.6	0.4	0.44	0.21	0.31
Electricity, Steam & Hot Water	7.33 (6.69)*	4.41 (3.8)*	2.84 (1.09)*	0.67 (0.67)*	2.29 (1.87)*	11.52 (9.55)*	2.66 (0.78)*	1.04 (0.95)*	1.13 (0.47)*	2.42 (1.88)*
Construction	0.21	0.25	0.5	0.1	0.6	3.02	1.07	0.78	0.43	0.43
Trade & Transport	0.25	0.19	0.43	0.14	0.46	1.72	0.4	0.49	0.18	0.3
Services	0.13	0.15	0.18	0.04	0.24	1.1	0.21	0.17	0.11	0.1
Overall	0.38	1.9	0.35	0.21	0.39	1.96	0.46	0.45	0.25	0.42

* Figures show the "total" energy consumption intensities, while there in brackets are "indirect" energy consumption intensities

sectors have the highest total energy consumption intensities among inter industry sectors. In Singapore, fishery sector has the highest total or indirect energy consumption intensities among its different inter industry sectors. In most of the countries, other typical sectors with high energy consumption intensities are non-metallic mineral products; metal products; chemical products. Additionally, either agriculture or the services sector has the lowest value of energy consumption intensity in most of the countries.

Among the ten countries, almost all the inter industry sectors of China have remarkably high values of energy consumption intensities compared to the same sectors of other countries. Overall, Singapore and then, Japan have the lowest total energy consumption intensity, while China and then, Malaysia have the highest one. The energy consumption intensity value of a sector in a country depends upon its own industrial structure (e.g., relative weight of unprocessed, semi-processed or finished goods producing sectors in the total national economy), efficiency of each sector's production technology, especially that of energy related technology. In addition, however, it depends upon the industrial structure and production technology of other sectors of the economy from which it receives goods and services required for its own output. Therefore, there is an interdependence among different inter industry sectors of different economies, and a straightforward comparison of energy consumption intensities of inter industry sectors of different countries cannot be done. Even so, an inter industry sector with high energy intensity can play an important role in and responsibilities for reducing its embodied energy. The reduction could be achieved alone or jointly with other inter industry sectors of an economy. In case of China, we can easily reach a conclusion that its inter industry sectors have extremely high consumption of energy per unit demand of goods and services compared with those of other countries.

Table 2 shows the sector wise total primary energy consumption responsibilities in each country. Among the ASEAN countries, Indonesia's total primary energy consumption is highest and that of Singapore shows the lowest value.

Among the ten countries, most of the inter industry sectors of the USA followed by China have remarkably high total primary energy consumption responsibilities compared to those of other countries. Inter industry sectors like construction; oil & natural gas; electricity, steam & hot water; trade & transport; services; food, beverages & tobacco etc. have high energy consumption responsibilities in most of these

Table 2 Total Primary Energy Consumption Responsibilities (10^5 TOE)

Inter Industry Sectors \ Countries	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	USA	ASEAN
Agriculture	3.7	0.9	0.6	0.05	1.8	176.1	2.1	3.7	13.8	150.9	6.9
Livestock	0.7	1.1	0.3	0.1	1.7	62	1	2.3	2.9	14.7	3.9
Forestry & its Products	1.4	0.7	1.3	0.4	1.6	74	2.9	1.2	8.9	53.6	5.3
Fishery	1.4	0.8	4.8	0.3	0.9	11.1	5.2	7.6	10.5	1.7	8.2
Oil & Natural Gas	52	36.5	12.8	32.2	8.5	113.5	17.5	61.7	483.2	4587.6	142
Mining (inc. coal)	-0.04	-0.5	2.8	-0.1	1.8	870.2	-4	7.9	-9.6	609.1	4
Food,Beverage & Tobacco	15.5	17.4	8.7	1.1	19	208.8	21.2	30.6	164.5	704.6	61.6
Textile,Leather & their Products	3.9	2.5	1.3	0.4	8.3	271.5	24.9	29.8	64	255.6	16.4
Pulp,Paper & Printing	0.8	0.3	0.5	0.1	0.4	32.1	2.3	2.2	17.6	169.1	2.2
Chemical Products	5.9	4.6	1.5	1.6	1.5	245	3.6	16.5	60.5	703.2	15.2
Rubber Products	1.5	5.5	0.3	0.3	0.5	24.2	0.6	5.6	6.7	35.3	8.2
Non-metallic Mineral Products	0.9	0.9	-0.2	0.0001	2.3	74.7	7.3	4.1	37.8	61.1	3.9
Metal Products	1.2	3.6	4.8	0.3	3.2	209.7	7.4	10.2	52.5	179.6	13
Machinery	1.4	1.5	3.2	1.3	2.2	577.1	27.2	25.9	294.7	585.6	9.6
Transport Equipments	6.5	1	1.4	0.2	3	192.1	13.7	17.7	170.2	699.1	12
Other Manufacturing	0.6	1.1	0.9	0.6	1.5	115.2	23	11	52.3	277.5	4.8
Electricity, Steam & Hot Water	84.5	16.6	11.2	1.8	12	175.6	27.5	11.7	278.8	2755.6	126
Construction	64	11.8	15.3	3.5	26.8	1702.8	62	126.7	913.2	1724.9	121.3
Trade & Transport	28.4	7.3	28.5	8.5	37.7	262.3	37.4	79	388.2	1856.6	110.5
Services	33.7	11	13.2	2.2	24.8	558.9	33.3	39.5	515.3	1786.3	84.8

countries. In China, other mining sector (inclusive of coal) has the highest energy consumption responsibility among its different inter industry sectors. Thus in each country, the inter industry sectors which have large responsibilities of primary energy consumption, are more or less similar although there is a large difference in their values. In any country, sector wise energy consumption embodied in goods and services has not necessarily followed the pattern of its respective energy consumption intensity. Because the energy consumption amounts in terms of goods and services of a sector depends upon its energy intensity as well as upon its final demand value.

4.2. Carbon Dioxide Emission

Table 3 shows the cumulative carbon dioxide emission intensity α', and indirect carbon dioxide emission intensity β', both expressed in terms of T-C/1000 US dollar of the above mentioned countries. Also, Table 4 shows the sector wise cumulative carbon dioxide emission responsibilities i.e., cumulative

Table 3 Carbon Dioxide Emission Intensities (T-C/1000 US Dollar)

Inter Industry Sectors \ Countries	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	USA
Agriculture	0.04	0.06	0.03	0.32	0.1	0.42	0.1	0.09	0.09	0.36
Livestock	0.06	0.13	0.04	0.06	0.17	0.28	0.16	0.23	0.1	0.3
Forestry & its Products	0.14	0.24	0.19	0.12	0.18	0.96	0.18	0.14	0.1	0.21
Fishery	0.11	0.14	0.23	0.63	0.63	0.42	0.38	0.41	0.29	0.57
Oil & Natural Gas	2.01 (1.09)*	2.77 (1.54)*	2.37 (0.1)*	0.51 (0.04)*	3.69 (0.41)*	11.59 (5.95)*	2.51 (0.20)*	3.23 (1.08)*	2.87 (0.23)*	3.73 (1.58)*
Mining (inc. coal)	0.4 (0.15)*	0.8 (0.34)	1.83 (0.36)*	0.52 (0.42)*	2.09 (0.36)*	40.31 (2.65)*	12.59 (0.97)	15.1 (0.32)*	10.13 (0.41)*	12.53 (1.85)*
Food,Beverage & Tobacco	0.07	0.21	0.08	0.11	0.2	0.62	0.17	0.19	0.11	0.24
Textile,Leather & their Products	0.17	0.31	0.09	0.07	0.17	1	0.19	0.3	0.13	0.29
Pulp,Paper & Printing	0.27	0.15	0.24	0.06	0.27	1.35	0.24	0.32	0.16	0.27
Chemical Products	0.54	0.33	0.23	0.35	0.25	3.49	0.3	0.64	0.31	0.9
Rubber Products	0.19	0.27	0.14	0.29	0.32	1.12	0.2	0.27	0.16	0.35
Non-metallic Mineral Products	0.47	0.46	0.63	0.17	0.98	4.55	1.46	2.26	1.2	1.25
Metal Products	0.42	0.43	1.36	0.07	0.58	4.57	0.55	0.64	0.29	0.66
Machinery	0.08	0.17	0.33	0.03	0.22	1.82	0.24	0.29	0.13	0.19
Transport Equipments	0.18	0.05	0.24	0.05	0.19	1.78	0.29	0.28	0.14	0.2
Other Manufacturing	0.1	0.28	0.32	0.1	0.12	1.45	0.24	0.39	0.14	0.24
Electricity, Steam & Hot Water	4.96	2.86	0.87	0.54	1.37	9.14	0.42	0.83	0.37	1.46
Construction	0.16	0.19	0.41	0.08	0.48	2.8	0.9	0.73	0.36	0.36
Trade & Transport	0.19	0.13	0.27	0.11	0.34	1.49	0.28	0.42	0.13	0.21
Services	0.09	0.1	0.1	0.03	0.17	0.99	0.13	0.14	0.07	0.07
Overall	0.27	1.36	0.23	0.17	0.29	1.8	0.29	0.4	0.18	0.3

* Figures show the "cumulative" carbon dioxide emission intensities, while in brackets are "indirect" carbon dioxide emission intensities

carbon dioxide supplied by each sector to final consumers in the countries through transaction of goods and services. The carbon dioxide emission intensities as well as the carbon dioxide emission responsibilities of most of the inter industry sectors in each country have nearly followed the patterns of their respective energy consumption intensities and energy consumption responsibilities, respectively. This is because fossil fuel based energy has captured the large share of total sector wise primary energy consumption in each of these countries.

In each country, the ratio of cumulative carbon dioxide emission to total energy consumption (T-C/

Table 4 Cumulative Carbon Dioxide Emission Responsibilities (10^5 T-C)

Inter Industry Sectors \ Countries	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	USA	ASEAN
Agriculture	2.7	0.6	0.4	0.04	1.3	154.6	1.3	3.3	10	111.9	5.1
Livestock	0.5	0.8	0.2	0.1	1.2	55.2	0.6	2	2	10.6	2.8
Forestry & its Products	1	0.5	0.9	0.3	1.2	66.5	1.6	1.1	6	39.1	3.9
Fishery	1	0.6	3.7	0.2	0.7	9.6	3.8	6.5	7.9	1.2	6.2
Oil & Natural Gas	39.1	27.6	10.2	25.9	6.5	92.2	13.9	52.6	371.7	3284.8	109.3
Mining (inc. coal)	-0.03	-0.4	2.6	-0.1	1.7	860.9	-3.9	7.8	-9.4	600.6	3.8
Food,Beverage & Tobacco	11.2	12.1	6	0.9	14	187.1	12.8	26.9	114	520.9	44.1
Textile,Leather & their Products	2.8	1.7	0.8	0.3	5.8	242.2	13.1	25.8	41.9	187.9	11.4
Pulp,Paper & Printing	0.6	0.2	0.4	0.1	0.3	28.8	1.3	1.9	11.8	125.5	1.6
Chemical Products	4.4	3.3	1.1	1.3	1.1	221.4	2.2	14.5	42.3	549.6	11.3
Rubber Products	1.1	3.8	0.2	0.3	0.4	21.7	0.3	4.8	4.5	26.4	5.7
Non-metallic Mineral Products	0.7	0.6	-0.1	0.0001	1.8	69.4	6.1	4	34.1	55.1	3
Metal Products	0.9	2.8	4.1	0.2	2.7	196.2	5.5	9.1	36.5	154	10.7
Machinery	1	1.1	2.5	1	1.7	523.9	17.8	23	196.7	449.8	7.2
Transport Equipments	4.6	0.7	0.9	0.1	2.2	174	9.1	15.6	114	542.9	8.5
Other Manufacturing	0.5	0.8	0.7	0.5	1.1	104.2	13.8	9.7	35.1	209.1	3.5
Electricity, Steam & Hot Water	57.1	10.8	3.4	1.4	7.2	139.3	4.4	9.4	90.9	1658.1	80
Construction	48	8.7	12.4	2.8	21.6	1576.7	52.4	118.7	763.7	1430.2	93.5
Trade & Transport	20.8	5.3	17.4	6.9	28.1	228.1	26.4	67.5	274	1291.2	78.5
Services	23.7	7.4	7.2	1.8	17.9	500.9	20	34.3	345.8	1287.6	58

TOE) is highest for mining (coal) sector and lowest for steam, electricity & hot water sector. Overall, this ratio is highest for China (0.92 T-C/TOE)and lowest for Taiwan (0.64 T-C/TOE) and then, for Philippines (0.66 T-C/TOE). In Singapore, this ratio is uniform for all sectors (0.8 T-C/TOE).

4.3. Energy Conservation and Reduction of Carbon Dioxide Emission in China

Based on the observation presented in 4.1 and 4.2, other Asian countries as well as China need to find ways to save energy and reduction of carbon dioxide emissions. Other Asian countries should reduce the emissions of carbon dioxide by increasing, mainly, the share of non-fossil/renewable energy sources as their first priority, whereas in China, both efficient energy conversion and conservation technologies and gradual reduction in the share of fossil fuel are very important.

In 1985, the average thermal energy conversion efficiency of Chinese power generation sector was nearly 28.6 % with equivalent fuel rate of 431 g/kwh [8]. However, the modern energy conversion technologies like atmospheric fluidized bed combustion (AFBC), pressurized fluidized bed combustion (PFBC) and integrated coal gasification combined cycle with the average thermal energy conversion efficiency of about 43 % are already available for commercial use in some advanced industrialized countries such as Japan.

If 50 %, 75 % and 100 % of the present stock of thermal energy conversion technology are replaced by more advanced ones as mentioned above, then the thermal energy conversion will be elevated to nearly 35.75 %, 39.3 % and 43 % and the overall savings in primary energy of about 3 %, 4 % and 6 % can be achieved, respectively. The reduction in carbon dioxide emission from the above savings that can be achieved are 3%, 5% & 6%, respectively. The above reduction is, still, nominal as large share of primary energy consumption is captured by other sectors of the economy.

4.4. Trade of Primary Energy and Carbon Dioxide Embodied in Goods and Services

Table 5 exhibits the trade of energy embodied in goods and services between the ten countries. Countries with largest amount of energy export are China, the USA, Indonesia and Japan, whereas, countries with largest amount of embodied energy import in terms of goods and services are Japan, the USA, Singapore and Korea, respectively. The ratio of import to the export of energy embodied in goods and services is largest for Singapore, and then for Japan, and it is smallest for China.

So far as trade of carbon dioxide is concerned, this has almost followed the pattern of its respective trade of embodied energy.

Thus, the countries like Singapore and Japan largely depend their primary energy consumption as well as carbon dioxide emission upon other Asian countries and upon the USA. Singapore and Japan have also large dependency for the use of environmental resources such as land through trade of goods and services [9]. Such dependency can be lowered substantially if the related sectors' intensities (e.g., energy) of those countries, exporting goods and services, are reduced.

Thus reduction in the intensities of energy or carbon dioxide of the traded goods and services is

Table 5 Trade of Primary Energy embodied in Goods and Services (10^5 TOE)

From \ To	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	USA	Total	Total Export	Import/Export
Indonesia	107.33	0.8	0.9	7.04	0.83	1.31	3.47	9.85	125.49	51.01	308.04	200.72	0.14
Malaysia	0.74	27.06	2.24	14.08	8.81	0.83	2.34	12.86	49.81	5.8	124.57	97.5	0.24
Philippines	0.14	0.23	100.23	0.74	0.32	0.6	0.48	0.72	6.45	3.23	113.13	12.9	2.57
Singapore	1.65	3.34	0.09	37.33	2.3	0.22	0.52	0.66	6.58	2.11	54.8	17.47	8.12
Thailand	0.27	0.42	0.6	0.56	148.12	0.61	0.54	0.43	3.05	4.76	159.35	11.23	3.27
China	7.58	10.51	8.98	98.85	14.38	5441.94	2.58	4.16	280.09	87.75	5956.83	514.89	0.09
Taiwan	1.34	0.8	1.43	2.73	0.95	2.67	270.62	1.87	10.33	23.51	316.24	45.62	2.41
Korea	1.15	0.8	1.22	1.54	0.95	0.38	1.29	476.35	33.27	18.84	535.79	59.44	1.85
Japan	7.01	3.27	1.97	4.74	3.92	22.2	9.76	22.06	3386.19	64.78	3525.9	139.71	5.36
USA	8.65	3.59	15.67	11.59	4.28	18.75	34.63	57.23	233.59	16823.6	17211.58	387.99	0.67
Total	135.85	50.81	133.34	179.19	184.84	5489.51	326.24	586.19	4134.86	17085.4	28306.23		
Total Import	28.52	23.75	33.11	141.87	36.72	47.57	55.62	109.84	748.67	261.8			

important. Techno-economical cooperation and trade liberalization among these countries are needed for achieving this policy objective. Thus attention should be given to an ecobalance of traded goods and services among countries.

5. Conclusions and Comments

For the year 1985, two calculations are made on energy consumption intensities of various inter industry sectors in the countries.

The first calculation assumes a closed national economy, in which any import of the energy in terms of goods and services in each country is neglected and export is attributed to each country's own consumption. Almost all the Chinese inter industry sectors have high energy consumption intensities, and their respective carbon dioxide emission intensities are also high compared to those of other countries. The overall ratio of carbon dioxide emission to energy consumption is also highest for China because coal based fossil fuel has the major share of total energy use in the country. Even by complete replacement of old thermal power generating technology in China, improvement in energy saving as well as the reduction of carbon dioxide emission would not be significant.

The second calculation deals the Asia- Pacific region comprising nine countries and the USA as a closed economy, taking into account the movement of embodied energy and carbon dioxide associated with international trade of goods and services within the region. Singapore and Japan are substantially responsible for energy consumption and carbon dioxide emission in other countries as they import energy intensive goods and services. However, the balance can be changed if the energy consumption or carbon dioxide emission intensities of the imported goods and services are reduced, and thus, techno-economic cooperation between the countries is essential for this purpose.

The present study has several deficiencies accuring from the limited availability of data. First, the Asia- Pacific region and the USA is treated as a closed economy. Calculations of energy and carbon dioxide etc. in terms of goods and services imported from, and exported to the rest of the world (ROW) is completely neglected as the input-output table for the ROW is incomplete. Thus the relation between the world trade and true global energy consumption and carbon dioxide emission responsibilities of the countries were not made clear. Second, in the currently available input-output table, the inter industry transactions (inclusive of energy sectors) are in monetary units, and therefore, the row of the primary energy sectors were converted into equivalent physical units, assuming that the price of the primary energy is uniform throughout an economy. However in practice, this may differ from sector to sector and at least the row of the energy sectors should be available in physical units for making an improved analysis. Moreover, the input-output table used in this study is for the year 1985, which is already a long time ago in the context of the rapidly changing world economy together with substantial technological progress. To analyze the present situation, a more up-to-date input-output table, preferably, with detail classification of the inter industry sectors is essential.

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