Transactions on Ecology and the Environment vol 21, © 1998 WIT Press, www.witpress.com, ISSN 1743-3541

Linkages and coupling effects of pollutant emissions and energy consumption in Taiwan

Sue J. Lin, Jeng F. Lee, Zhu C. Chang
Dept. of Environmental Engineering, National Cheng-Kung University, 70101, Tainan, Taiwan
Email: t15197@mail.ncku.edu.tw

Abstract

Input-output modeling and multiplier analysis are used to assess the linkages and coupling effects between pollution emissions and energy consumption of major industries in Taiwan. A set of air pollutant criteria, including SO_2, NO_x and CO_2 are used as pollution indices to evaluate relationships between energy consumption and pollutant emission. Results indicate that energy consumption has strong coupling effects to intensify the level of air pollution. The sectors including road transportation, "other industrial chemicals", cement, paper, plastic materials, artificial fibers, non-metallic mineral products and steel are identified as the most significant industries causing serious air pollution in Taiwan. Therefore, energy efficiency and conservation programs should be enhanced for industries causing serious air pollution in Taiwan. Methods for doing this include: upgrading the industrial structure, improving industrial processes, strengthening energy management and providing technical assistance for better energy usage and environmental quality.

1 Introduction

Energy is the major support for industrial development. Due to economic development, energy consumption in Taiwan grew rapidly in the past four decades. However, large amounts of air pollutants, such as

Transactions on Ecology and the Environment vol 21, © 1998 WIT Press, www.witpress.com, ISSN 1743-3541

SO_2 and NO_X, also emitted from using energy, resulted in serious air pollution problems. Moreover, in response to the Kyoto Protocol of Framework Convention on Climate Change (FCCC), CO_2 mitigation has became an inevitable task for Taiwan. Therefore, energy conservation and pollution reduction should be important goals of industrial development, in addition to assurance of economic gain.

In dealing with environment and energy, Leontief[1] initiated input-output analysis for computing pollutant emission and evaluating control strategies for major industries in the U.S. James[2] modified the input-output model to find quantitative relationships between energy uses and pollutant emission. Breuil[3] employed a fixed-coefficient input-output model to estimate SO_2 and NOx emission by combustion and industry processes in French industry. Hawdon and Pearson[4] used a 10-sector input-output model structure based on inter-relationships between energy, environment and economic welfare to estimate the air pollution emission coefficients in the U.K. Proops et al.[5] examined the UK economy and lifecycle implications of eight types of electricity generation for the emissions of CO_2, SO_2 and NOx by using input-output method.

This study differs from the above studies in that it uses an integrated approach, including direct coefficient analysis, input-output modeling and multiplier analysis, to assess linkages and coupling effects between pollutant emissions and energy consumption, and to identify the sectors with high pollution emissions in Taiwan.

2 Methods

2.1 Framework of Input-output Analysis

Input-output analysis is a quantitative method used to analyze mutual inter-relationships among various sectors in an economic system. Each sector's production process can be represented by a vector of structural coefficients that describes the relationship between the input it absorbs and the output it produces. Leontief[1] indicated that the inter-dependence between the sectors of a given economy system can be defined by a set of linear equations to express the balances between the total input and the aggregate output of each product and service. The basic equations of the input-output model can be presented as:

Transactions on Ecology and the Environment vol 21, © 1998 WIT Press, www.witpress.com, ISSN 1743-3541

$$\sum_{j=1}^{n} X_{ij} + F_i = X_i \quad (1)$$

$$\sum_{j=1}^{n} X_{ij} + V_j = X_j \quad (2)$$

$$\sum_{j=1}^{n} a_{ij}X_j + F_i = X_i \quad (3)$$

where,

X_i = total gross output produced in sector i
X_j = total gross input required in sector j
F_i = product of sector i delivered to the final demand
V_j = final payment (value added) by sector j
x_{ij} = the product amount of sector i used by per unit output of sector j
a_{ij} = x_{ij}/X_j, the direct input of sector i into sector j

Thus, the technical structure of the entire system can be represented by the matrix of technical input-output coefficients of all its sectors. Equation (3) can be rewritten in the following matrix form:

$$AX+F=X \quad (4)$$
$$(I-A)X=F \quad (5)$$

or

$$X=(I-A)^{-1}F=[b_{ij}]F \quad (6)$$

where,

A = the direct input coefficient matrix of a_{ij}
I = the identity matrix
$(I-A)^{-1}$ = the Leontief inverse matrix
b_{ij} = representing the total direct and indirect requirement of sector i by per unit output of sector j to final demand.

2.2 Pollution and Energy Multipliers

As pollution is regarded as the "externality" of regular economic activities, many forms of pollutant emission can be related in a measurable way to energy consumption or production processes. For example, the quantity of SO_2 released in the air is related to the nature and amount of fuel and to the technological characteristics of a particular industry. In this study, the "externalities" can also be incorporated into the conventional input-output model in order to respond to the environmental effects of energy consumption by industry processes. A set of air pollutant criteria, including SO_2, NOx and CO_2 are used as pollution indices to evaluate relationships between pollutant emission and energy consumption.

The energy multiplier was first applied by Wright[6] for defining the energy commodity in input-output analysis. Also, Miller and Blair[7] elaborated the energy and environmental input-output model to quantify the total impact of energy commodity input coefficients and pollutant output coefficients. In this study, the total impact of the pollution coefficient and the energy coefficient were calculated by the following equations:

$$P = \dot{P}\,(I-D)^{-1} \tag{7}$$

$$E = \dot{E}\,(I-D)^{-1} \tag{8}$$

where,

E = total impact of energy coefficient, which specifies the amount of energy required directly and indirectly by per one million worth of final demand of industry j (10^7 kcal/million NT$).

P = total impact of pollution coefficient, which specifies the amount of pollutant emitted directly and indirectly caused by per one million worth of final demand of industry j (ton/million NT$).

$\dot{E}$ = energy coefficient, which specifies the amount of energy required directly by per one million worth of output of industry j (10^7 kcal/million NT$).

$\dot{P}$ = pollution coefficient, which specifies the amount of pollutant emitted directly caused by per one million worth of output of industry j (ton/million NT$).

$(I-D)^{-1}$= the Leontief inverse matrix for the domestic portion

3 Data Consolidation

The basic input-output table for 1994 used in this study was originally developed by the Accounting Office of the Executive Yuan in Taiwan[8]. The original 150-sector table was then aggregated into a 34-sector table.

Since the focus of this study is on the interrelationships of domestic industry productivities, the domestic gross output of all industries was used. Also, SO_2, NO_X and CO_2 were selected as pollution indices, since the acid rain and global warming received most of the attention among other environmental problems. The pollution coefficients, describing tons of SO_2 and NO_X emitted by each industry per million dollars' worth of its total output, were calculated based on

Transactions on Ecology and the Environment vol 21, © 1998 WIT Press, www.witpress.com, ISSN 1743-3541

AP-42 emission factors[9] and were adjusted accordingly for local conditions. The estimation of CO_2 emissions was consistent with the IPCC guidelines[10] and data was adjusted to the fuel inventory in Taiwan, including fuel density, and carbon content of motor gasoline, diesel and fuel oil. The energy coefficients for each sector were calculated based on data from the "Taiwan Energy Balance Sheets"[11].

4 Results and Discussion

4.1 Coupling Effects of Pollution and Energy Coefficient

The pollution and energy coefficients for all 34 sectors were computed, and the results for some primary sectors were listed in Table 1. Road transportation has the highest energy intensity. This means that this sector consumes the largest amount of energy per unit worth of product. Also, it ranks the highest for NO_X, and second for CO_2 emission coefficients (Table 1). SO_2 coefficient of this sector ranks eighth in all 34 sectors because oil is the main energy type used by this sector, and the sulfur content of oil has been reduced to a very low value.

Table 1 Coupling effects of energy and pollution coefficients

Sector	Energy[1]	CO_2[2]	SO_2[2]	NO_X[2]
Road Transportation	32.341(1)	95.108(2)	0.093(8)	1.105(1)
Other Industrial Chemicals	32.295(2)	112.076(1)	0.709(1)	0.243(3)
Petrochemical Materials	31.869(3)	27.370(9)	0.060(14)	0.018(16)
Cement	17.947(4)	72.759(3)	0.114(6)	0.285(2)
Non-Metallic Mineral Products	14.324(5)	49.910(4)	0.246(2)	0.119(4)
Oil Refineries	12.578(6)	33.415(6)	0.072(11)	0.032(10)
Steel	9.266(7)	34.276(5)	0.082(9)	0.035(9)
Paper	8.013(8)	31.576(8)	0.204(4)	0.091(7)
Artificial Fibers	7.431(9)	32.525(7)	0.212(3)	0.116(5)
Plastic Materials	6.568(10)	26.794(10)	0.191(5)	0.106(6)

Notes: 1.Unit: 10^7 Kcal/NT\$$10^6$ 2.Unit: ton/NT\$$10^6$ 3.The number within bracket means the ranking in all 34 sectors.

In addition to road transportation, other industrial chemicals, petrochemical materials, cement and non-metallic mineral products are also among the top five in energy consumption compared to other sectors. Among these five sectors, pollution coefficient of petrochemical materials is not significantly high due to part of energy being used as process material, which does not emit pollutants. Except for petrochemical materials, the other four sectors are higher in rankings for both CO_2 and NO_X emission coefficients; this indicates the fact that energy has strong coupling effects to intensify the level of air pollution.

Sectors of other industrial chemicals, non-metallic mineral products, artificial fibers, paper and plastic materials, which all use large amount of coal as fuel, are among the top five with high SO_2 coefficient. Cement does not rank consistently among the top five with regard to SO_2 emission coefficient because SO_2 can be absorbed by cement during the production processes.

4.2 Relationships of Energy and Pollution Multipliers

The total (direct and indirect) impacts of energy coefficients for all 34 sectors were computed according to equation (8), and some primary results are illustrated in Table 2. Petrochemical materials, "other industrial materials", road transportation, cement and plastic materials are among the top five in energy multiplier compared to other sectors. It is noticeable that petrochemical materials, not road transportation, ranks as the highest energy multiplier. This implies that petrochemical materials induce much more indirect energy consumption than road transportation. "Other industrial chemicals" ranks highest for CO_2 pollution multiplier, third for NO_X pollution multiplier, and second for energy multiplier. Road transportation ranks third for both energy multiplier and CO_2 pollution multiplier, and highest for NO_X pollution multiplier. As for the SO_2 multiplier, "other industrial chemicals", artificial fibers, non-metallic mineral products, paper and plastic materials are the top five compared to other sectors.

Results also show that the rankings for energy multiplier and three kinds of pollution multiplier are not completely consistent. For example, road transportation demonstrates high energy, CO_2 and NO_X multiplier, but the ranking for SO_2 multiplier is the 13th among 34 sectors. Also, artificial fibers ranks sixth for energy multiplier, but second for SO_2 multiplier. This is mainly caused by the variety of fuel composition for each sector.

Transactions on Ecology and the Environment vol 21, © 1998 WIT Press, www.witpress.com, ISSN 1743-3541

Table 2 Results of energy and pollution multipliers

Sector	Energy[1]	CO_2[2]	SO_2[2]	NO_X[2]
Petrochemical Materials	41.856(1)	42.366(9)	0.109(14)	0.044(26)
Other Industrial Chemicals	40.260(2)	131.141(1)	0.799(1)	0.294(3)
Road Transportation	35.244(3)	103.814(3)	0.114(13)	1.147(1)
Cement	26.432(4)	104.261(2)	0.182(7)	0.424(2)
Plastic Material	21.105(5)	44.584(8)	0.244(5)	0.137(7)
Artificial Fibers	20.390(6)	57.103(6)	0.326(2)	0.184(4)
Non-Metallic Mineral Products	18.942(7)	65.118(4)	0.301(4)	0.182(5)
Steel	17.057(8)	62.748(5)	0.162(9)	0.091(10)
Oil Refinery	13.572(9)	36.422(10)	0.081(21)	0.042(29)
Paper	13.504(10)	51.441(7)	0.309(3)	0.160(6)

Notes: 1.Unit: 10^7 Kcal/NT$$10^6$ 2.Unit: ton/NT$$10^6$ 3.The number within bracket means the ranking in all 34 sectors.

5 Conclusions

According to the experiences of major industrialized countries, the enhancement and improvement of environment quality have became inevitable trends. Consequently, sustainable development of environment should be combined with energy and economical goals when programming industrial development strategies. This study applies input-output method and multiplier analysis to identify coupling effects of pollutant emissions and energy consumption from major industries in Taiwan.

Results of this study indicate that sectors such as other industrial chemicals, cement, road transportation, non-metallic mineral products, steel and artificial fibers are identified as having high CO_2 emission. Other industrial chemicals, artificial fibers, paper, non-metallic mineral products, plastic materials and textiles and products are identified as being high in SO_2 emission. Road transportation, cement, other industrial chemicals, artificial fibers, non-metallic mineral products and paper are sectors with high NOx emission. The above findings are consistent with results of multiplier analysis which illustrate that petrochemical materials, other industrial chemicals, road transportation, cement, plastic materials and artificial fibers are sectors with very low energy efficiency. Among these sectors, pollution coefficients of

Transactions on Ecology and the Environment vol 21, © 1998 WIT Press, www.witpress.com, ISSN 1743-3541

petrochemical materials are not significantly high due to part of energy being used as process material, which does not emit pollutants. Therefore, energy efficiency and conservation programs should be enhanced for industries causing serious air pollution in Taiwan. Methods for doing this include: upgrading the industrial structure, improving industrial processes, strengthening energy management and providing technical assistance for better energy usage and environmental quality. Meanwhile, technological changes and economic incentives can play important roles in both expanding and declining sectors to shift the industry structure toward more services and high-technology manufacturing which should result in lower energy demand and less pollution.

References

[1] Leontief, W., Environmental repercussions and the economic structure: an input-output approach, *Review of Economics and Statistics*, **52**, pp. 262-271, 1970.

[2] James, D. E., A system of energy accounts for Australia, *Economic Record*, **56**, pp. 171-181, 1980.

[3] Breuil, J. M., Input-output analysis and pollution emissions in France. *Energy Journal*, **13**, pp. 173-184, 1992.

[4] Hawdon, D. & Pearson, P., Input-output simulations of energy, environment, economy interactions in the U. K., *Energy Economics*, **17**, pp. 73-86, 1995.

[5] Proops, J. L. R. & Gay, P. W. & Speck, S. & Schroder, T., The lifetime pollution implication of various types of electricity generation: An input-output analysis, *Energy Policy*, **24** (3), pp. 229-237, 1996.

[6] Wright, D., Energy budgets 3. Goods and services: an input-output analysis, *Energy Policy*, **2**, pp. 307-315, 1974.

[7] Miller, R. E. & Blair, P. D., *Input-Output Analysis Foundation and Extensions*, Englewood Cliffs, New Jersey: Prentice-Hall, 1985.

[8] Accounting Office of Executive Yuan, *Taiwan Inter-Industry Input-Output Linkage Table (150 Sectors) — Year 1994*, Taipei, Taiwan: Executive Yuan, 1996.<in Chinese>

[9] Environmental Protection Agency, *Compilation of Air Pollution Emission Factors (AP-42)*, U.S. Environmental Protection Agency, Research Triangle Park, 1995.

[10] IPCC/OECD, IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 1,2 and 3, 1994.

[11] Energy Commission, Ministry of Economic Affairs, *Taiwan Energy Balance Sheets – Year 1995*, Taipei, Taiwan: Ministry of Economic Affairs, 1995.<in Chinese>