ELSEVIER

Energy Policy. Vol. 24, No. 3, pp. 221–228, 1996

0301-4215/96 $15.00 + 0.00

0301-4215(95)00133-6

The CO_2 mitigation options for the electric sector

A case study of Taiwan

Hsunling Bai and Jong-Hourm Wei

Institute of Environmental Engineering, National Chiao-Tung University, 75, Po-Ai Street, Hsin-Chu, Taiwan

A linear programming model is presented to evaluate the effectiveness of possible CO_2 mitigation options for the electric sector. The options being considered are fuel alternatives, energy conservation, reduced peak production, improved electric efficiency and CO_2 capture technologies. The results indicate that energy conservation can significantly reduce CO_2 emissions only when combined with reduced peak production and improved electric efficiency. The cost effectiveness of installing CO_2 capture and disposal devices was compared to that of fuel alternative plan. It is concluded that the installation of CO_2 capture and disposal devices can be an effective and economic option.

Keywords: CO_2 control strategies; Fuel alternatives; CO_2 capture technologies

The global warming problem is raising international concerns among developed and developing countries. As estimated by the Intergovernmental Panel on Climate Change (IPCC, 1990), CO_2 is the most important greenhouse gas, making over one-half of the contribution to climate change. After the Earth Summit, many countries in the Organization for Economic Cooperation and Development have published their preliminary national polices on CO_2 emission reductions, with decisions fixing the amount of CO_2 emission in the year 2000 to at least no more than that in 1990. For example, the USA and Canada tend to hold their total CO_2 emissions in 2000 to earlier (eg 1990) level of emissions, while Japan and France will fix their CO_2 emissions on a per capita basis.

For countries not listed in the Annex I parties of the IPCC, the Climate Change Convention does not have a rigorous restriction on the levels of their CO_2 emission reductions. This indicates that CO_2 emissions in 2000 may not necessarily be reduced to the level of 1990 for less developed countries and newly industrialized countries. However, for newly industrialized countries such as Taiwan, the impact of adopting CO_2 mitigation options on the economic growth rate is still a primary concern of our energy policy.

It is well known that the damage induced by climate change can only be estimated with huge uncertainty. The effectiveness of CO_2 control strategies as well as their economic impacts can also be estimated only within a large range of uncertainty. Therefore, studies on the CO_2 mitigation options are usually limited to evaluating their individual effectiveness (Blok *et al*, 1993; Yamaji *et al*, 1993; Huang, 1993; Herzog, 1994). Recently during the revision of this paper, several papers have been published which address the cost-effectiveness of CO_2 control strategies (Morthorst, 1994; Maya and Fenhann, 1994; Amous *et al*, 1994; Mahgary *et al*, 1994; Halsnæs *et al*, 1994). They reported that negative marginal abatement costs are possible via the employment of appropriate CO_2 control options. These options include energy conservation, fuel substitution, use of renewables, increasing of GHG sinks etc.

In this paper, a multiobjective linear programming model is proposed to assist in evaluating the cost impacts of several possible CO_2 mitigation options for the electric sector as well as the associated CO_2 emission reductions. With the base year of 1990, this model is applied to study the best short-term (to the year 2000) solution for Taiwan's electric sector in order to accomplish maximum possible CO_2 reduction with minimum cost. The CO_2 emission data are presented as per capita emissions.

Mitigation options

CO_2 control strategies for the electric sector may include one or more of the following options: a carbon tax, CO_2 emission standard, fuel alternatives, electric energy conservation, reduced peak production, improved electric efficiency and CO_2 capture technologies. The employment of a tax policy and CO_2 emission standard are regulations but not the actual means which lead to CO_2 emission reduction. The carbon tax and CO_2 emission standard as determined by the government depend on the cost-effectiveness of other CO_2 mitigation options. They are therefore not considered in this study. The CO_2 mitigation options evaluated in this paper are fuel alternatives, electric energy conservation, reduced peak production, improved electric efficiency and CO_2 scrubbing devices. These options are described below.

Fuel alternatives

Fuel substitution can be done for both existing and new power plants. It is achievable for existing plants but with high retrofit costs. The cost for retrofitting a power unit may be even higher than that for installing a new power unit, while a fuel alternative plan for new power plants is easier and economic to accomplish. Although power generation by hydropower and other renewable energy emits no CO_2, it would be difficult to drastically increase the percentage of power generation by renewable energy in a short period. Therefore the focus of fuel alternative options will aim at an optimization of new fossil fuel firing units, and adoption of a new 2000 MW nuclear plant.

Electric energy conservation

The definition of energy conservation from the electric sector is that it is a measure which leads to a decreased consumption of electricity but does not reduce the level of the activity for which the electricity is used. Electricity energy consumption in 1990 was 8.7×10^{10} kWh in Taiwan. The associated CO_2 emission was about 36 Mt from the electric sector, which accounted for about 31% of the total CO_2 emission in 1990. Projected electricity energy demand is 14.8×10^{10} kWh in 2000. As a result of comparison between Taiwan and other developed countries on the gross national product per unit of electricity used (GNP/ GWh) (Taiwan Energy Statistics, 1993; International Energy Statistics, 1992), a maximum energy conservation rate of 35% is achievable in the long term. But in the near future such as in 2000, the energy conservation goal rate as designated by the Taiwan government is around 10% (Tzeng, 1992). In this study an electric energy conservation rate of 0–20% is employed to evaluate its effectiveness in CO_2 emission reduction.

Reduced peak production

The total installed nameplate capacity for new units is reduced by a reduction of peak production; it is therefore also possible to reduce CO_2 emission. However, it requires some incentives such as time zoning of the electricity charge. The range of reduction rate on the peak production employed in this study is 0–10% (Wei, 1994).

Improved electric efficiency

Electric efficiency can be improved by an increase in thermal efficiency and in the operation efficiency of the power plant. Since a significant improvement in thermal efficiency in the near future is not easy and its associated cost is difficult to estimate, the present paper aims at studying the effect of improving power plant operation efficiency on CO_2 emission reduction, which requires a negligible cost as compared to a power unit installation cost. As a result of better training of power plant operators, the possibility of power unit malfunction due to human factors is greatly reduced, and the capacity factor of a power unit is thus increased. A possible range of 0– 10% (Tzeng, 1992) for improving electric operation efficiency is used in this study.

CO_2 removal technologies (end of pipe option)

Available CO_2 removal technologies are liquid solvent (eg MEA) scrubbing, solid adsorbents, separation processes, and CO_2 recycle etc (Booras and Smelser, 1991; Kreith *et al*, 1991). Although CO_2 emissions from thermal plants could be reduced significantly by the above technically feasible processes, the costs are enormous and uncertain. Given the lack of local CO_2 treatment data for Taiwan, the results of recent studies on the CO_2 treatment and disposal costs from other countries are evaluated.

The engineering contractor Bechtel in the UK (Rose, 1993) estimated that the total cost, including CO_2 capture in the power plant and its disposal in the ocean, would be US$30–180 per tonne of avoided carbon emissions, while the cost, as estimated in a US study (Herzog, 1994), ranges from US$18 to US$37 per tonne of CO_2 captured for various types of power plant, and the CO_2 disposal costs were estimated to be US$15–50 per tonne of CO_2 disposed. Therefore, the total costs of CO_2 treatment and disposal were in the range of US$33–87 for every tonne of avoided CO_2 emission. These studies concluded that CO_2 capture and disposal techniques, although technically feasible, are still too expensive to be used as a CO_2 mitigation option.

System optimization

The conflict between economic development and environmental protection is always a subject of argument. The electric power company tends to select the option that leads to a minimum power generation cost, but environmentalists will force them to choose the one that causes minimum damage to the environment. Therefore there are two objectives in this study.

The first objective is the economic approach which is to minimize power plant installation and operation costs; the second objective is the environmental approach to minimize CO_2 emission from the electric sector. However, as a result of conflict, the final decision may fall somewhere between these two objectives. The multiobjective linear programming model is then to,

$$\text{Minimize } Z_1 = \sum_{i=1}^{4}\sum_{j=1}^{3} C_i N_{ij} \quad (1)$$

$$\text{Minimize } Z_2 = \sum_{i=1}^{4}\sum_{j=1}^{3} R_i N_{ij} \quad (2)$$

where

Z_1 = new power plant installation cost
Z_2 = CO_2 emissions from new installations
C_i = generation cost of unit i
N_{ij} = electricity generation of new unit i designed for load j
R_i = CO_2 emission per unit of power generation
i = 1: coal-fired unit
i = 2: oil-fired unit
i = 3: LNG-fired unit
i = 4: nuclear fuel unit
j = 1: base load
j = 2: middle load
j = 3: peak load

The above two models are subject to the following constraints:

(1) Satisfaction of electricity demand in 2000:

$$\sum_{i=1}^{4}\sum_{j=1}^{3}\left(E_{ij} + N_{ij}\right) + W = D \quad (3)$$

where

E_{ij} = electricity generation of existing unit i for load j
W = percentage of power generation from hydro power plants and renewable energy (estimated as 10% of total power generation in this study)
D = electricity demand

(2) Satisfaction of base, middle and peak load requirement:

$$T * L_b \le \sum_{i=1}^{4}\left(e_{i1} + n_{i1}\right) + W_1 \le T * U_b \quad (4)$$

$$T * L_m \le \sum_{i=1}^{4}\left(e_{i2} + n_{i2}\right) + W_2 \le T * U_m \quad (5)$$

$$T * L_p \le \sum_{i=1}^{4}\left(e_{i3} + n_{i3}\right) + W_3 \le T * U_p \quad (6)$$

$$T = \sum_{i=1}^{4}\sum_{j=1}^{3}\left(e_{ij} + n_{ij} + W_j\right) \quad (7)$$

where

T = total installed nameplate capacity
L_b = lower limit of base load generation ratio
U_b = upper limit of base load generation ratio
L_m = lower limit of middle load generation ratio
U_m = upper limit of middle load generation ratio
L_p = lower limit of peak load generation ratio
U_p = upper limit of peak load generation ratio
W_j = installed nameplate capacity from hydro power and renewable energy
e_{ij} = installed nameplate capacity of existing unit i for load j
n_{ij} = installed nameplate capacity of new unit i for load j

(3) Satisfaction of peak production and reserve margin:

$$T \ge P(1 + B) \quad (8)$$

where

P = peak production
B = percent reserve margin, 20% used in this study

(4) Relationship between installed nameplate capacity and energy generation:

$$E_i = e_i * h * f_i \quad (9)$$

$$N_i = n_i * h * f_i \quad (10)$$

where

h = hours per year (= 8760 hr)
f_i = capacity factor of plant i

(5) Non-negative decision variables:

$$N_{ij} \ge 0, n_j \ge 0 \quad (11)$$

Results and discussion

Fuel alternative plan

Table 1 shows the results of CO_2 emissions in 2000 and associated new power unit installation costs. Results are

Table 1 Predicted results of CO_2 emissions in 2000 and corresponding new power unit costs based on fuel alternative plan

	Without nuclear plant		With nuclear plant	
	Minimize cost	Minimize CO_2 emission	Minimize cost	Minimize CO_2 emission
Total CO_2 emission (10^6 Mt)	89.6	77.8	78.5	67.3
Per capita CO_2 increase rate (%) (compared to 1990)	127	97	99	70
CO_2 emission reduction rate (%) (compared to base case)[a]	Base case	13	12	25
Total cost for new units (10^6 US$)	3800	4700	3700	4600
Cost in US$ per tonne of CO_2 avoided (compared to base case)	Base case	76	–9	36

[a]The base case is the uncontrolled emission in the year 2000, ie 89.6 Mt.

shown in terms of two objectives (minimizing cost and minimizing CO_2 emission) under conditions of with and without a 2000 MW nuclear plant installation. For the case with the objective of minimizing the new unit cost but without a new nuclear plant, the total CO_2 emission is 89.6 Mt, which corresponds to a 127% increase of per capita CO_2 emission as compared to 1990. This is the uncontrolled amount of CO_2 emission in 2000 from the electric sector, and will be used as the base case for comparison. If the objective were to minimize the CO_2 emission, the corresponding CO_2 emission increase rate would be 97% on a per capita emission basis. This is about a 30% per capita emission reduction as compared to the uncontrolled emission.

If the proposed 2000 MW nuclear plant can be installed and operated by 2000, the CO_2 emission increase rate is 99% on a per capita emission basis with the objective of minimizing cost. The amount of CO_2 emission reduction achieved by a 2000 MW nuclear plant is about the same as that by a fuel alternative plan based on minimizing the CO_2 emission. Therefore, if the objective of minimizing CO_2 emission is in conjunction with a new nuclear plant, the CO_2 emission reduction rate is about doubled.

In order to evaluate the cost-effectiveness of the fuel alternative plan, the costs per tonne CO_2 avoided were calculated from the differences of the costs of new unit installation and the amounts of CO_2 emission from the case of uncontrolled emission. The results are shown in the last row of Table 1. It is seen that for the case of minimizing cost and in conjunction with a new nuclear plant, the cost of CO_2 emission reduction is negative. For every tonne of CO_2 avoided, the benefit is US$9 as compared to the base case. This is due to the low power generation cost for a nuclear plant as compared to other thermal plants, and is one of the reasons why Taiwan's government plans to have a nuclear plant installed by 2000. However, a huge number of people in Taiwan are objecting to the nuclear plant, which may overturn it. If a new nuclear plant is not possible, the marginal cost of CO_2 reduction is about US$76 with the objective of minimizing CO_2 emission.

Energy conservation

Since uncertainty remains as to whether one more nuclear plant will be built in Taiwan, the following discussion will focus on conditions without a new nuclear plant. Figure 1 shows the CO_2 emission reduction rates as achieved by electric energy conservation. The cost of energy conservation was not considered in this study. The base case of 0% CO_2 emission reduction is obtained from the uncontrolled emission as discussed previously. The two curves shown in Figure 1 represent the two objectives of minimizing CO_2 emission and minimizing unit installation cost respectively. As can be seen for an energy conservation rate less than around 10%, an increase in the energy conservation rate does yield an increase in the CO_2 emission reduction. However, as the energy conservation rate increases to larger than 10%, its effectiveness on the CO_2 emission reduction disappears. This is due to constraints on the satisfaction of the peak production as well as the percentage requirement of each load. Although electric energy is conserved to a certain degree, the peak production as well as the loading percentages may not be satisfied at the same time. Therefore, the same capacity of new power units may be required although electric energy is conserved. As a result, the potential amount of CO_2 emission may not be changed.

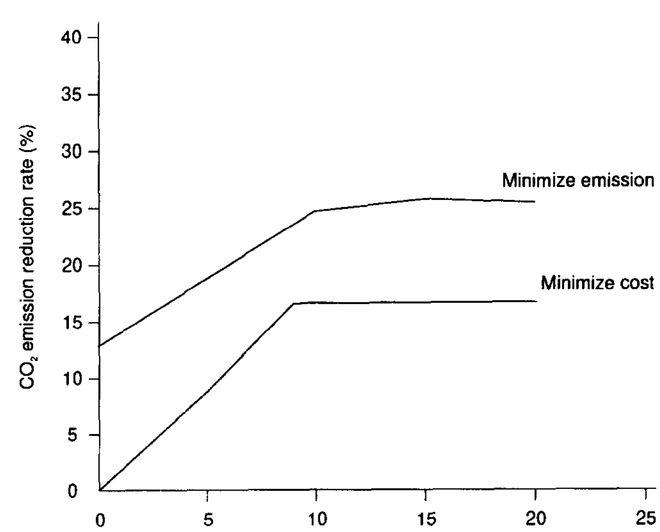

Figure 1 The CO_2 emission reduction rate in 2000 as compared to uncontrolled emission achieved by electric energy conservation

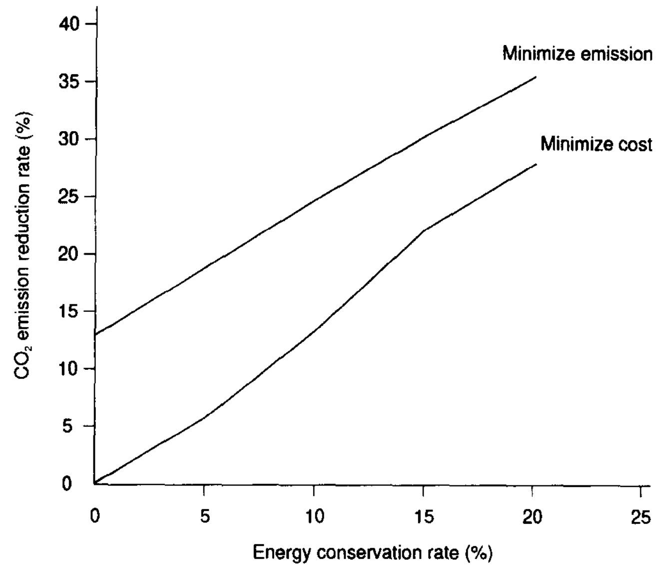

Figure 2 The CO_2 emission reduction rate in 2000 as compared to uncontrolled emission achieved by electric energy conservation plus 10% reduction on peak production

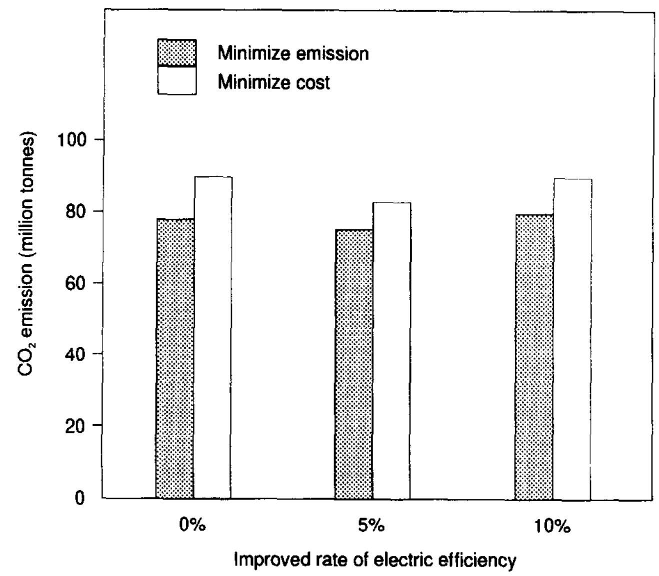

Figure 3 The CO_2 emissions in 2000 as achieved by increasing electric operation efficiency

Energy conservation and reduced peak production

The effect of 10% reduction on peak production along with the energy conservation on the CO_2 emission reduction is shown in Figure 2. It is seen that under the objective of minimizing CO_2 emission, the CO_2 emission reduction rates for energy conservation rates less than 10% are the same as the results shown in Figure 1. While the energy conservation rates are higher than 10%, a continuous CO_2 emission reduction is observed in Figure 2. This was not seen in Figure 1 without simultaneous reduction of peak production. A similar observation is seen for the objective of minimizing the cost of new installations.

Improved electric efficiency

Figure 3 shows the effect of improving electric operation efficiency on the CO_2 emission reduction. The increased rates of electric operation efficiency under consideration are 0%, 5% and 10%, respectively. The CO_2 emission is slightly reduced under a 5% improvement of electric operation efficiency. However, if the improved rate of electric operation efficiency was 10%, the CO_2 emission may be even higher than that without any improvement. The benefit of improving the electric operation efficiency lies in the fact that it may reduce the cost of new power units. As indicated in Figure 4, the cost for new power units has its minimum value at a 5% improvement in the electric operation efficiency, whether the objective was based on minimizing CO_2 emission or minimizing cost. The new unit cost under a 10% improvement in electric efficiency is higher than that at 5%, but still lower than that at 0%. This is due to the constraint on the satisfaction of peak production, although an improvement in the electricity operation efficiency yields a higher value of electricity supply under the same unit installation capacity. However, the peak production must be satisfied at the same time, and more power units may still be needed, which results in increases in the CO_2 emission and power generation costs.

Combination of the options

It has been shown previously that the options of energy conservation, reduced peak production, and improved electric efficiency may not yield a profound reduction on the CO_2 emission if only one of them is imposed on electric utilities. Under some cases the potential CO_2 emission from each option may even increase. However, when the three options are combined, the results are different. According

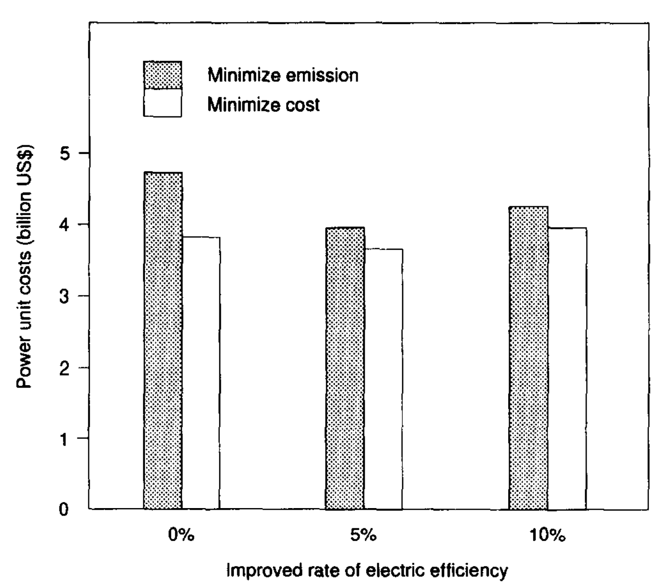

Figure 4 The costs of new power unit installation in 2000 as achieved by increasing the electric operation efficiency

to the designated goal in 2000 by the Taiwan Council of Energy Commission Ministry, the energy conservation can be achieved at a rate of 10% and the reduced rate of peak production will be 10%. Table 2 shows the results on the combined option of the designated goal plus a 5% increase in the electric operation efficiency in 2000. The total amounts of CO_2 emission without an introduction of a nuclear plant are 71.7 and 65.4 Mt, respectively, with the objectives of minimizing cost and minimizing CO_2 emission. As compared to the uncontrolled emission (base case shown in Table 1), the CO_2 emission reduction rates are 20% and 27%, respectively, with the objectives of minimizing cost and CO_2 emission reduction. Compared to previous results on the individual effects of each of the three options, the combination of these three options offers better CO_2 removals and lower unit installation costs.

The results of intermediate solutions (A and B) on the fuel alternative plan are also shown in Table 2; their CO_2 emissions and unit installation costs fall between those based on minimizing cost and minimizing CO_2 emission. Using the objective of minimizing unit installation cost as the new base case, the marginal costs of CO_2 reduction were calculated for the other three solutions. The costs for these three fuel alternate plans are US$42, 43 and 53 for every tonne of CO_2 avoided, respectively, for intermediate solutions A, B and the objective of minimizing CO_2 emission. These values are significantly lower than that of minimizing the CO_2 emission shown in Table 1 without introducing a new nuclear plant (US$76 per tonne CO_2 avoided). Therefore if combination of the three options can be achieved in 2000, the fuel alternative plan is a more cost effective option for CO_2 emission reduction.

Cost effectiveness of fuel alternative plan and CO_2 capture technologies

Is the fuel alternative plan or is the installation of CO_2 capture devices an economic option for CO_2 emission reduction? The answer is clear if the alternative fuel is nuclear fuel since it has the lowest power generation cost and emits no CO_2. However, due to social and political concerns, nuclear plants may not be built. If the alternative fuel is the low CO_2 emitted LNG or light oil, then the answer depends on the cost effectiveness of the two options. The amounts of CO_2 emission shown in Table 2 can be further reduced by installing CO_2 capture and disposal devices. Since the objective of minimizing the unit installation cost was used as the new base case, the marginal cost of CO_2 removal for the base case is simply the CO_2 capture and disposal cost. The marginal costs of CO_2 removal for the other three solutions were obtained from the differences of the total costs (including unit installation and CO_2 capture and disposal costs) and total amounts of CO_2 emission from the base case. The results are shown in Figures 5a, 5b and 5c for high, low and intermediate CO_2 capture and disposal costs, respectively. The cost effectiveness is shown as a function of total CO_2 emission from the electric sector in the year of 2000.

The CO_2 capture and disposal cost was set to be at a high value of US$76 per tonne of CO_2 removed in Figure 5a. It is seen that the marginal cost of CO_2 removal was always lower for the fuel alternative plan aimed at minimizing the CO_2 emission. Therefore, it is economic to select the fuel alternative plan which minimizes CO_2 emission instead of CO_2 capture and disposal devices. However, as also indicated as a dotted line in Figure 5a, the fuel alternative plan results in the best achievement of 65.4 Mt of CO_2 emitted to the atmosphere. A further reduction of the CO_2 emission must also rely on the CO_2 capture devices.

On the other hand, the opposite results are shown in Figure 5b as the CO_2 capture and disposal cost was set at a low value of US$33 per tonne CO_2 removed. The fuel alternative plan aims at minimizing the unit installation cost yields the lowest cost for every tonne of CO_2 avoided. Therefore in order to achieve the same amount of CO_2 emission reduction, it would be beneficial to select the fuel plan that minimizes the unit installation cost, and then install CO_2 capture devices to avoid the CO_2 emission.

If the CO_2 capture and disposal cost is at an intermediate value such as US$50 for every tonne of CO_2 removed, the best solution turns out to be the fuel alternative options which lies between minimizing cost and minimizing CO_2 emission as indicated in Figure 5c. However, it is also seen that if the total CO_2 emission in 2000 were to be held the same as in 1990 (ie 36 Mt), the differences between each option in terms of costs per tonne CO_2 avoided become less significant.

Summary and conclusions

In this paper a linear programming model was presented which is useful for studying the effectiveness of possible

Table 2 Predicted results of CO_2 emissions in 2000 and corresponding new power unit costs based on combined options of 10% energy conservation, 10% reduction on peak production and 5% increase in electric efficiency without the introduction of a nuclear plant

	Minimize cost	Minimize CO_2 emission	Intermediate solution A	Intermediate solution B
Total CO_2 emission (10^6 Mt)	71.7	65.4	70.1	68.6
Per capita CO_2 increase rate (%) (compared to 1990)	82	66	78	74
CO_2 emission reduction rate (%) (compared to uncontrolled emission)	20	27	22	23
Total cost for new units (10^6 US$)	2790	3120	2860	2925
Cost per tonne of CO_2 avoided (US$) (compared to base case)	Base case	53	42	43

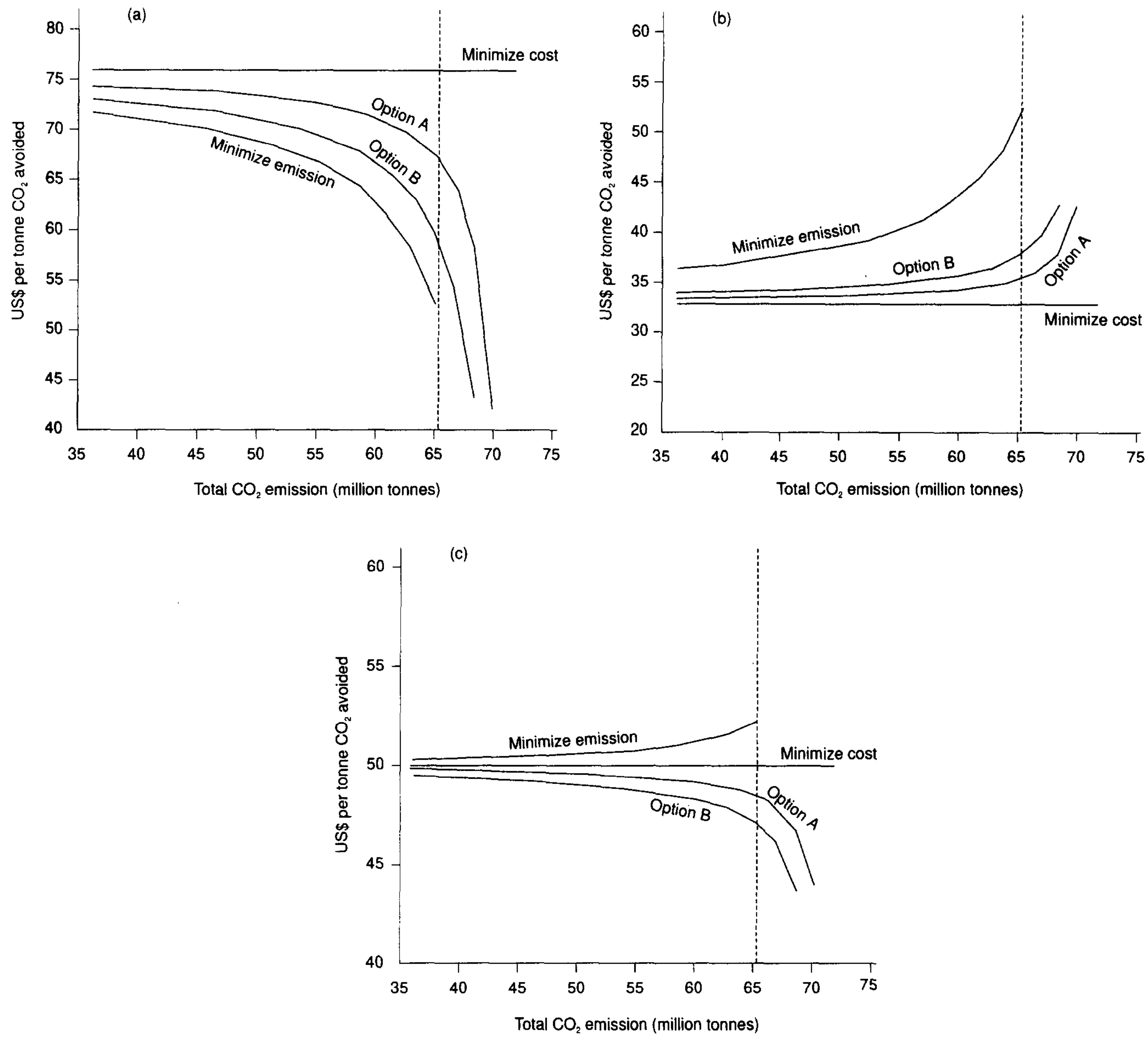

Figure 5 Marginal costs as achieved by fuel alternatives and CO_2 capture technologies in 2000. CO_2 capture and disposal cost is (a) US\$76, (b) US\$33 and (c) US\$50 per tonne of CO_2 capture

CO_2 mitigation options for the electric sector. The model was applied to evaluate the best solution for Taiwan's power plants in order to reduce the CO_2 emission in 2000 with minimum costs. The mitigation options being considered were fuel alternatives, energy conservation, reduced peak production, improved electric efficiency, and CO_2 capture technologies. The results indicated that without considering cost effectiveness, fuel alternatives for new power units are an effective means of reducing the CO_2 emission. The options of energy conservation, reduced peak production, and improved electric efficiency may not yield a profound reduction on the CO_2 emission if employed separately. However, by combining any of the reduced peak production and improved electric efficiency with the energy conservation, the CO_2 emission as well as the new unit installation cost can be significantly reduced. This also results in an increase in the cost effectiveness of the fuel alternative plan. The cost effectiveness of installing CO_2 capture and disposal devices and fuel alternative plans were also compared. It was seen that for a relatively low CO_2 capture and disposal cost (less than about US\$40 for every tonne of CO_2 avoided), it may be beneficial to select the power units which burn high CO_2 emitted fuels, then install the CO_2 capture and disposal devices to reduce the emission.

Acknowledgements

Support from the National Science Council, ROC through a grant number NSC 83-0410-E-009-024 is gratefully acknowledged. The authors would like to thank Miss G W Chang for assistance in preparing part of the illustrations.

The results represent the views of the authors and do not necessarily represent the options, policies or the recommendations of Taiwan's governmental agencies.

References

Amous, S, Revet, D and Sokona, Y (1994) 'Greenhouse gas abatement in Senegal' *Energy Policy* **22** (11) 947–954

Blok, K, Worrell, E, Cuelenaere, R and Turkenburg, W (1993) 'The cost effectiveness of CO_2 emission reduction achieved by energy conservation' *Energy Policy* **21** (6) 656–666

Booras, G S and Smelser, S C (1991) 'An engineering and economic evaluation of CO_2 removal from fossil-fuel-fired power plants' *Energy* **16** (11) 1295–1305

Halsnæs K, Mackenzie, G A, Swisher, J N and Villavicencio, A (1994) 'Comparable assessment of national GHG abatement costs' *Energy Policy* **22** (11) 925–934

Herzog, H (1994) 'CO_2 mitigation strategies: how realistic is the capture and sequestration option?' Paper 94-RA113.02, presented at the 87th Annual Meeting and Exhibition of the Air and Waste Management Association, Cincinnati, Ohio, 19–24 June

Huang, J P (1993) 'Energy substitution to reduce carbon dioxide emission in China' *Energy* **18** (3) 281–287

International Energy Statistics (1992) Energy Commission Ministry of Economic Affairs, Republic of China

IPCC (1990) *Policy Makers Summary of the Scientific Assessment of Climate Change* Report to IPCC from Working Group, Meteorological Office, Bracknell, UK

Kreith, F, Norton, P and Brown, P (1990) 'A comparison of CO_2 emissions from fossil and solar power plants in the United States' *Energy* **15** (12) 1181–1198

Mahgary, Y El, Ibrahim, A-F, Shama, M A-F, Hassan, A, Rifai, M A-H, Selim, M, Gelil, I A, Korkor, H, Higazi, A, Amin, A, Bedewi, F and Forsström, J (1994) 'Costs of CO_2 abatement in Egypt using both bottom-up and top-down approaches' *Energy Policy* **22** (11) 935–946

Maya, R S and Fenhann, J (1994) 'Methodological lessons and results from UNEP GHG abatement costing studies' *Energy Policy* **22** (11) 955–963

Morthorst, P E (1994) 'Constructing CO_2 reduction cost curves' *Energy Policy* **22** (11) 964–970

Rose, J (1993) 'Disposing of CO_2 from fossil-fueled power plants' *Environmental Science and Technology* **27** (7) 1282–1283

Taiwan Energy Statistics (1993) Energy Commission Ministry of Economic Affairs, Republic of China

Tzeng, S-H (1992) *The Energy Conservation Potential and Economical Assessment of CO_2 Control Strategies* Energy Report, April (in Chinese)

Wei, J-H (1994) *Short Term CO_2 Mitigation Options for Electric Utilities in Taiwan* MS thesis, National Chiao-Tung University, Taiwan

Yamaji, K, Matsuhashi, R, Nagata, Y and Kaya, Y (1993) 'A study on economic measures for CO_2 reduction in Japan' *Energy Policy* **21** (2) 123–132