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EVALUATION OF ALTERNATIVES TO INCREASE THE ELECTRICAL GENERATION CAPACITY OF THAI SUGAR MILLS

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Abstract—Five possible schemes have been considered for increasing the electricity-generation potential of sugar mills, including the uses of a bagasse dryer, cane trash to operate the mill power plant during the non-milling season and change from the existing back-pressure turbine to single or double extraction-condensing turbines. Five alternatives are compared on the basis of seven criteria: (i) private-sector investment, (ii) government-sector investment, (iii) operating cost of the total generating system, (iv) SO_2 emission from the power plant, (v) employment generation, (vi) dependence on foreign assistance, and (vii) local availability of the system components. A decision analysis (Analytical Hierarchy Process, AHP) is used to show that the single and double extraction-condensing turbine systems are preferred because of relatively low government investment, operating cost and SO_2 emission.

INTRODUCTION

The Electricity Generating Authority of Thailand (EGAT), a state enterprise responsible for electricity generation for the whole country, forecasts that the average annual growth of electricity demand will be 725 MW during the period 1992–1996 and 800 MW during 1997–2001.[1] To keep pace with the increasing demand, EGAT has to spend approximately 4 billion dollars during the next 5 yr.[2,3] Since this level of investment will take an unacceptably large part of the total foreign borrowing, the govenment plans to encourage participation of the private sector in electricity generation. Among the various technology options for the private sector, cogeneration appears to be the most interesting technology due to its very high fuel-utilization effectiveness.

Sugar mills, where expertise and equipment for electricity generation already exist, appear to be in a particularly advantageous position to participate in the private power-generation program. At present, there are 46 sugar mills in Thailand with a total capacity of 338,000 tons of cane per day.[4] The fiber part delivered from the milling of sugar cane is bagasse and is normally used to produce steam for process heat and electricity generation.

The bagasse is approximately 30% by weight of the crushed cane.[5] Based on the total annual cane production of 36 million tons,[6] roughly 12 million tons of bagasse will be produced per year. About 90% of the bagasse is used to generate heat and power for the factory and only 10% will be available for additional electricity generation. According to a model[7] based on actual data for 32 sugar mills, it should be possible to obtain up to 25% surplus bagasse with minor modifications. This estimation was confirmed by a trial program at the Petch Sugar Mill during the milling season of 1989–1990.[8] Thus, a total of excess bagasse of about 2.7 million tons could be available for private electricity generation.

In addition to bagasse, there is also a large amount of cane trash, i.e., cane tops and leaves, that could be used as a supplementary fuel. The cane trash, amounting to about 8.6 million tons/yr,[9] is at present left in the field without burning. In this study, five alternatives to increase

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the generation capacity of sugar mills are considered. The surplus electricity from the mills would be sold to the utility grid to lower the expansion rate of EGAT.

THE ALTERNATIVES

... alternatives for improvement of sugar-mill operation are considered. (i) The *base case* is the normal operation of the existing sugar mills power plant. At present the sugar mills are usually connected to the grid. Therefore, if there is any surplus electricity, they can sell to the grid. (ii) The *bagasse drying system* leads to improvement of the efficiency of the power plant of the sugar mill by decreasing the moisture content of the bagasse fired in the existing boiler. (iii) The *cane-trash system* is used to extend the operational period of the sugar-mill power plant into the non-milling season. After the available cane trash is consumed, the mill will stop operation for annual maintenance. This system would require equipment to collect the cane trash from the sugar-cane fields and a fuel-preparation unit. (iv) The *SECST system* will replace existing power-plant system with a new high-pressure boiler and a single extraction-condensing steam turbine which can supply process steam at 1.5 bar while some of the old boilers still remain to supply steam at 17 bar. During the non-milling season, the old boiler will not operate and the new extraction-condensing steam turbine will run at a fully condensing mode. In view of the very high investment cost, it is proposed to operate the system during the non-milling season, as well using cane trash as a fuel. (v) The *DECST system* uses high-pressure boilers together with a double extraction-condensing steam turbine to replace all of the existing low-efficiency power plant. The new power plant will run in the fully condensing mode during the non-milling season using cane trash as a fuel.

THE HIERARCHY STRUCTURE

From the government's perspective, it is necessary to consider not only the financial aspects of a project but also the effect of the project on society and the environment. Thus, the decision analysis should take into consideration economic, social and the environmental impacts of the project. The hierarchy structure is illustrated in Fig. 1.

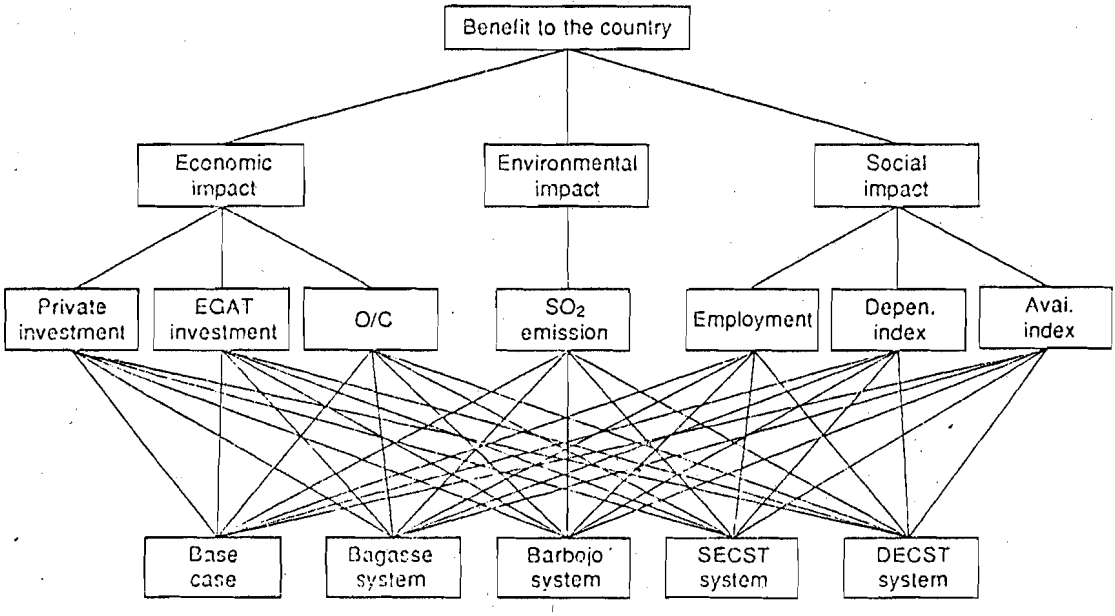

Fig. 1. The hierarchy structure of the study.

Financial criteria

The power-generation alternatives considered are compared on the basis of costs for private investment, EGAT investment and annual operating cost. (i) The *private investment* represents the improvement cost for the 46 sugar mills in Thailand in order to apply the alternative. (ii) The *EGAT investment* represents the government's investment in the power sector to provide adequate electricity to maintain the high economic growth rate of the country. (iii) The *operating cost* covers both the private and EGAT on a yearly basis. The operating cost of the system is an important factor that indicates the economic feasibility of a project.

Environmental impact criteria

Only SO_2 emission of the power plant will be considered to assess the environmental impact of the different alternatives.

Social impact criteria

The social impact is the most difficult part in the trade-off analysis. Three sub-criteria have been considered: (i) The *employment generation* of the sugar mill will reduce the movement of low-level workers from rural to urban areas which causes problems in the cities. (ii) The *dependency index* is a measure of the extent of dependency of a power-generation system on foreign assistance. A preferred system should be easy to operate and maintain without foreign assistance. This criterion would be particularly important at times of crisis. The dependency index is given on a 0–1 scale. The experienced engineers from both EGAT and the sugar mill were asked to evaluate the dependency index for each alternative. (iii) The *local availability index* represents the local availability of the components of a power-generation system. A preferred system should have a high value of this index since the use of local components would promote local industry and save foreign exchange.

A CANE-TRASH SYSTEM

After cane harvesting, the cane trash will be allowed to continue to dry for 4–6 days. The moisture content of the cane trash will drop from 50 to 30% or less.[10] The cane trash will then be collected and put into a baler that is pulled by a hired tractor. The baled cane trash will be moved to an outdoor storage site with a hydraulic loader. When needed, the bales will be transported to the mill, opened and shredded into uniform small pieces and fed into the boilers.

Private investment

The investment in the private sector falls into the two categories field and mill-modification equipment. Field equipment consists of a raker, baler and hydraulic loader. The estimated cost for each is presented in Table 1. It is convenient to consider the field equipment per set of baler, which consist of one raker, one baler and a loader shared by two balers. The cost per set of the baler is US$ 19,309. The estimated baler collecting capacity is based on actual observations[13] and is given in Table 2. In order to use the baled cane trash as a fuel, the mill must have additional fuel-preparation equipment, which includes a bale processor to open the

Table 1. Estimated field-equipment costs (in 1989 US$); source Refs. 11, 12.

Equipment	Capacity (ton/hr)	Price [US$]
Raker	15	3,384
Baler	15	14,452
Loader	1	3,000

Table 2. The field capacity of cane-trash collecting equipment; source Ref. 13.

Equipment	Capacity
Baler capacity	15 tons/hr
Field efficiency	70 %
Length of working day	8 hr
Cane trash availability	80 %
Daily capacity	62.7 tons/day

cane-trash bale, a shredder to shred the cane trash to small pieces, and a grinder for further size reduction. The estimated costs are shown in Table 3.

Assuming a linear relation, the cost of the fuel-preparation system is US$ 2820 per 1 ton/h of capacity. The installed cost of the fuel-preparation system is estimated as US$ 4230 per 1 ton/h of capacity. The investment for the cane-trash system in all 46 sugar mills is US$ 27 million. The efficiency of the sugar mill power plant, using cane trash as a supplementary fuel, was evaluated. The overall potential for electricity generation from cane trash in Thai sugar mills is 2140 GWh.

EGAT investment

The annual peak demand of EGAT will be increased by 725 MW_e and the increase in energy demand is 4950 GW_eh per year. EGAT proposes to install a generation capacity of 934 MW annually. The extra capacity is to substitute for some old power plants that have to be retired and to increase the reserve capacity of EGAT which is below the desired standard.[1] If the private sector cannot supply the electricity to the grid, EGAT must expand its generation capacity. On the other hand, if the private sector can supply a part of the increase in demand, EGAT's responsibility is only to supply the rest. The average cost for a power plant with zero tax, proposed by EGAT, is US$ 801,600 per MW of installed capacity.[1] From the detailed calculation for 46 Thai sugar mills, the total generation capacity with the cane-trash system will be 313 MW and the electricity generation 2140 GWh. EGAT will then have to install the additional 621 MW and produce 2810 GWh at a cost of about 498 million dollars.

Operation cost

Table 4 illustrates the estimated operating cost for the private sector. The total operating cost for 46 sugar mill is 51.4 million dollars per year.

The operating cost for an EGAT power plant varies from plant to plant. The average operating cost is US$ 30,610/GWh[16] and the total operating cost for 2810 GWh is 86.0 million dollars.

SO_2 emission

The calculated SO_2 emission is based on the actual amount of electricity generation from each type of EGAT power plant. Table 5 illustrates the SO_2 emissions from the various types of power plants.

Table 3. The estimated price of fuel-preparation equipment (in 1989 US$); source Ref. 14.

Equipment	Manufacturer	Capacity (ton/hr)	Price [US$]
bale processor	John Deer	6	8,500
Shredder	Silver Engineering	15	15,000
Shredder	Champion Products	30	29,000
Grinder	Who Co.,Ltd.	25	81,000

Table 4. The operating cost for the private sector; source Ref. 15.

Items	Cost
Field labor cost	0.215 $US/ton
Mill labor cost	
- small mill	516 $US/ton
- large mill	624 $US/ton
Tractor hire cost	0.766 $US/ton
Tractor fuel cost	1.518 $US/ton
Transportation	2.80 $US/ton
Cane trash cost	1.20 $US/ton
Maintenance cost	5 % of capital

Employment

The employment of EGAT power plants is evaluated for the present and projected needs.[17,20] The average number of EGAT employees per MW of generating capacity is 4.59. Thus, the additional number of employees needed is 3310, which is equivalent to 1.2 million man-days/yr. The employment in the private sector includes the field workers who collect and transport the baled cane trash and the additional workers who handle the fuel-preparation system. According to Ref. 21, the number of people needed to collect cane trash in the field is 1 man-day for 5 tons of cane trash. Therefore, the total additional employment in sugar-cane field is 1.1 million man-days/yr. The number of workers needed for the power-plant section of the sugar mill is[22] 132 for a large mill and 105 for a small mill. The total number of needed workers in all of the mills is 2.2 million man-days/yr. Therefore, the total employment for this alternative is 4.5 million man-days/yr.

Foreign-dependency index

The foreign dependency is calculated for each alternative and each sub-component. This dependency is weighted according to capital investment and evaluated by the sugar-mill and by EGAT engineers. The index for both the private sector and EGAT is divided into installation and maintenance components, with each part given a weight of 0.5. It has been found that the installation of an additional fuel-preparation system requires strong foreign assistance (0.6) while maintenance requires little assistance (~0). On the other hand, EGAT needs more foreign assistance during installation (0.75) and also some assistance (0.15) during maintenance. The sample calculation for the foreign-dependency index is shown in Table 6.

Local availability index

The local availability of each alternative is considered component by component and weighted by the investment costs of the private sector and EGAT. The availability of the

Table 5. The SO_2 emission from power plants; source Refs. 17–19.

Type of Power Plant	Electricity GWh/year	SO_2 Emission ton/year
Hydro	315	0
Bunker oil	250	3,420
Diesel oil	1	~0
Natural gas	1,603	~0
Lignite	597	62,327
Purchased	44	0
Private sector	2,140	18,480
Total	4,950	84,227

Table 6. The dependency index of the cane-trash system.

Sub-component	Percentage by investment cost	Dependency index
Cane Trash system	4.8	0.048x0.5x0.6 = 0.014
- installation (0.5)		0.048x0.5x0.0 = 0.0
- maintenance (0.5)		
EGAT power plant	95.2	0.952x0.5x0.75 = 0.357
- installation (0.5)		0.952x0.5x0.15 = 0.071
- maintenance (0.5)		
Total dependency index		= 0.442

Table 7. The availability index of the cane-trash system.

Sub-component	Percentage by investment cost	Availability index
Cane trash system	4.8	0.048x0.9 = 0.043
EGAT power plant	95.2	0.952x0.4 = 0.381
Total availability index		= 0.424

components for the cane-trash system is 0.9 and that of the EGAT plants is 0.4. The availability index is given in Table 7.

COMPARISONS OF ALTERNATIVES

The results of our analysis are shown in Table 8. For the base case (alternative 1), no private investment is needed while EGAT's investment is the highest at US$ 749 million. For use of the DECST system (alternative 5), the private sector investment is US$ 1796 million while EGAT needs no investment at all. The foreign-dependency index for the fifth alternative is the highest because high-pressure boilers and a double extraction-condensing turbine need to be installed at the sugar mills. Employment generation is high for the third alternative because the existing sugar-mill power plants are used during the non-milling season. The older power plants require many workers to operate the system.

THE DECISION ANALYSIS

Five decision makers (DM) were interviewed consisting of the representative each from EGAT, sugar mill, National Energy Administration, Office of Cane and Sugar Board and an energy engineer. Thus decision maker have been designated DM1, DM2, DM3, DM4, and DM5 respectively. The decision analysis was conducted according to Analytic Hierarchy

Table 8. Comparison of the selected alternatives.

Sub-criteria	Base case	Bagasse drying	cane trash system	SECST system	DECST system
Private Investment MUS$	0	32	27	1,767	1,796
EGAT Investment MUS$	749	749	498	20	0
Operating Cost MUS$/y	139	139	137	81	76
SO_2 Emission k ton/y	110	109	84	43	43
Employment M-Man-day/y	2.1	2.2	4.5	2.5	2.4
Dependency Index	0.45	0.43	0.44	0.68	0.69
Availability Index	0.40	0.42	0.42	0.21	0.21
Electricity potential GWh	388	467	2,140	7,732	8,006

Table 9. The overall score for the decision alternatives in each alternative.

Alternative	DM1†	DM2	DM3	DM4	DM5
Base case	0.196	0.081	0.085	0.200	0.174
Bagasse drying system	0.200	0.089	0.104	0.141	0.163
Cane trash system	0.204	0.139	0.117	0.176	0.210
SECST system	0.208	0.323	0.349	0.235	0.197
DECST system	0.192	0.328	0.345	0.248	0.257

† DM1 = representative from the National Energy Administration. DM2 = representative from the Office of Cane and Sugar Board. DM3 = representative from the Electricity Generating Authority of Thailand. DM4 = Energy Engineer. DM5 = representative from the Sugar Mill.

Process (AHP) with the hierarchy structure as shown in Fig. 1. The Expert Choice software[23] was used to analyze the result from the interviews. The outputs from the program are summarized in Table 9. The result of the decision analysis can be summarized as follows. (i) The most preferred alternatives for all decision makers are the SECST and DECST system. The SECST alternative is the most interesting alternative from the point of view of DM1 and DM3 while DECST is of the most interest to DM2, DM4 and DM5. (ii) Although the total investment, EGAT plus private sector, of the SECST and DECST alternatives are much higher than the other alternatives, the decision makers considered them as the most appropriate alternatives mainly because of the reduction in EGAT investment, lower operating cost and much lower SO_2 emission. (iii) Most of the decision makers give the highest weight to the economic criterion, with some giving high weight to EGAT investment sub-criterion while others give high weight to private investment sub-criterion.

CONCLUSIONS

(i) The base case of private power generation corresponds to the highest EGAT investment, operating cost, and SO_2 emission. It is the least preferred option of two of the five decision makers interviewed. (ii) The bagasse drying system would require only little private investment but has little or no difference from the base case in terms of operating cost, SO_2 emission, employment, dependency and local availability. (iii) The cane-trash system would require the lowest total government and private investment and generate the highest level of employment. (iv) The SECST system would require a very high level of private sector investment and causes the least SO_2 emission. (v) The DECST system would require the highest level of the private investment, result in the least SO_2 emission, and is the most preferred system of three of the five decision makers interviewed. (vi) The maximum electricity generation potential of the sugar mills in Thailand is 8006 GWh using the DECST system.

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