A Holistic Approach to Energy Technology Evaluation in Thailand

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ABSTRACT

The paper proposes a holistic approach to energy technology evaluation. Quantitative measures such as cost efficiency, contribution to GDP, national employment contribution, contribution to public revenue, contribution to rural economy, and environmental and health impacts are developed to compare alternative energy technologies with conventional coal-fired technology. A national objectives consistency score is developed to serve as the basis in energy technology evaluation. The study shows that alternative energy technologies such as industrial biomass cogeneration, small hydro, wind and solar PV contribute more to GDP, national employment, public revenue and rural development than traditional large-scale coal fired power plant while at the same time reducing the impact on the environment and human health as well as reducing the dependence on imported fuels. Small hydro, wind and solar energy technologies however require strong support from the government due to high economic costs.

1. INTRODUCTION

Thailand is endowed with abundant renewable energy resources that could be used to generate electricity. As this ASEAN country recovers from the economic crisis, it will continue to expand its electricity generation capacity. The Electricity Generating Authority of Thailand (EGAT) plans to meet increased electricity demand using natural gas combined-cycle and conventional coal-fired power plants. While the National Energy Policy Office (NEPO) has recently announced a number of incentives and programs for the development of alternative energy resources, energy technologies are still typically evaluated using traditional least-cost approaches. This paper proposes a holistic approach to energy technology evaluation in Thailand, in which technologies are evaluated against national socio-economic objectives. Quantitative measures are developed to compare a number of alternative energy technologies with conventional coal-fired technology. The approach is easy to implement, which makes it appropriate for routine low-cost preliminary evaluation of energy projects in developing countries with national socio-objectives similar to those of Thailand.

While estimates of economic and social impact of new energy technologies can be found in the literature [1-4], the assumptions underlying the studies are often different from one study to another, making comparison across technologies difficult. In addition, very few studies are holistic in nature.

They either overlook or disproportionately emphasize the social, environmental, or economic dimensions. In this paper, a common set of assumptions is used for all technologies and all results are reported per kWh to allow direct comparison.

The results show that industrial biomass cogeneration is a very competitive alternative to conventional coal-fired technology when social, economic, and environmental costs are taken into account. Significant development of other alternative technologies such as wind, solar PV, and small-hydro will require strong support from the government because of high economic costs despite favorable social and environmental impacts. The support of small hydropower projects and related emerging technologies also appear very consistent with Thailand's broader national socio-economic objectives.

2. A HOLISTIC APPROACH TO ENERGY POLICY AND TECHNOLOGY

Adequate energy supply is a prerequisite for economic growth. Hence, the goal of energy policies and projects is generally to consistently supply sufficient energy or power at low prices to meet the demand. As a result, power development projects are generally selected using a discounted investment and operation and maintenance (O&M) cost minimization approach. This is arguably what is being done in many emerging economies, resulting in large scale centralized power projects except in the most remote and unpopulated areas of these countries.

A holistic approach requires decision-makers to view energy policy as only one component of a coordinated national policy, such that energy projects are evaluated with respect to all national policy objectives. Clearly, national policy objectives in most emerging economies are much broader than simply supplying the cheapest production factors to create economic growth. A review of economic and social development goals in emerging Asian countries following the Asian crisis reveals [5] that national objectives consistently include (a) improving the balance of payment, (b) stimulating employment, (c) strengthening rural development because of increasing disparities with urban areas, (d) supporting innovation and the development of new industries, and (e) protecting the environment [6].

In order for energy project and policies to be consistent with broader economic and social objectives in Thailand, energy technologies should thus be assessed using the analytical framework presented in Figure 1.

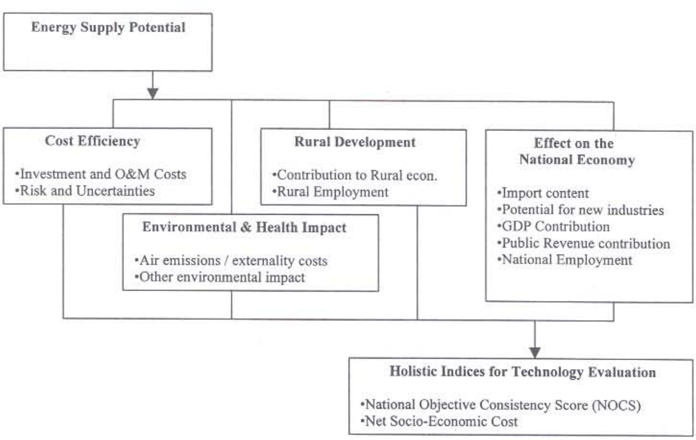

Fig. 1. A holistic model of energy technology evaluation.

3. ALTERNATIVE ENERGY SUPPLY POTENTIAL

Renewable energy technology under consideration in Thailand include solar PV, solar thermal, wind energy, biomass CHP, biogas, mini-hydro (200 kW-600 kW), and geothermal. This study does not include geothermal and biogas because of their limited potential in Thailand, neither does it include solar thermal because of the currently low demand for heat in individual households and its limited industrial applications. Wind energy is included in the study because of its technical and economic potential if locations with fast wind speeds can be identified. Hybrid systems, i.e. systems that combine two or more energy technology for electricity generation, are not considered.

3.1 Wind Energy Potential

Currently the installed capacity is less than 200 kW, including one 150 kW turbine in Phuket Island. The potential for wind power in Thailand is limited because available data suggests that wind speeds rarely meet the minimum of 5 m/s to 6 m/s required for operation and cost effectiveness of wind turbines. Indeed, Phuket is one of the areas with the largest wind speed at about 4.6 m/s. Some potential may exist for off-shore wind energy generation, where wind speeds are typically 50% greater than in-land. While the potential in Thailand is low, Yamamoto and Ando [7] points out that wind velocity varies considerably from one location to the next and that local wind studies are necessary before rejecting wind technology as a major energy source in Thailand.

3.2 Solar PV Energy Potential

Current PV applications in Thailand include: (a) PV for electrification through solar home systems and central power plants, (b) PV for battery charging stations, and (c) PV for water pumping [8]. The combined capacity of PV projects total 4.4 MW_p. The annual average of mean daily solar radiation in Thailand is high at about 4.6 $kWh/m^2/day$, and with some areas receiving as much as 8 hours of sunshine hours per day [9]. Overall, the solar PV potential is far greater than that of any other new renewable sources of energy in the long term.

3.3 Industrial Combined Heat and Power (CHP) Potential

The technical industrial CHP potential, where technical potential refers to the power potential if all biomass residues in Thailand are utilized as fuel, is estimated at 10,000 MW of electrical power, mostly in the agro-food sector. A recent survey of agro-food industries in Thailand by Ramboll [10] reveals that 65% of the companies already operate some type of cogeneration system. However, the actual production of power by these companies amount to only 17% of the structural power potential, where structural power potential refers to the power capacity that could be installed in mills that have processing capacity above the minimum thresholds for which CHP energy systems are appropriate.

The replacement of low pressure boilers commonly used in the agro-food industries by high efficiency biomass cogeneration systems alone would result in at least 3,000 MW of electrical power given the current structure of these industries [11]. The sugar, rice, palm-oil and wood industries all have significant technical as well as structural power potential. Current energy consumption in the industrial sector is characterized by reliance on centrally produced electricity as well as fuel consumption for production of process heat. Hence, implementation of CHP, which produce both electricity and process heat, could result in fuel savings of up to 30% of total 1997 fuel consumption in power production [6].

3.4 Mini and Micro Hydro-power

The installed capacity of mini and micro hydro-power systems (from less than 100 kW up to 6 MW) in Thailand is about 48 MW. The Thai Department of Energy Development and Planning (DEDP) has current plans for implementation of an additional 100 MW. For comparison, small hydropower in China has been growing at rates between 7% and 13% per year during the last 20 years for a current installed capacity of over 17,000 MW [12]. Estimations of the technical potential for mini and micro hydropower in Thailand range from 500 MW to 8,000 MW or more.

This technology has been somewhat ignored in Thailand relative to some other alternative technologies, perhaps because there is no major manufacturer of this type of technology in developed countries with an interest in exporting the technology to Asia. Another reason may be the extremely large fluctuations in rainfall between the rainy and dry seasons in some areas of Thailand, which can significantly complicate implementation and effectiveness of small hydropower systems [7].

4. DATA AND METHODS

The first component of the model is an evaluation of the energy potential of alternative energy technologies. Information on currently installed capacity and potential was gathered through expert interviews and a review of the existing literature. The second component is an evaluation of cost efficiency of each technology for which energy potential exists. In order to compare the technologies, technical-economic data was collected from energy projects considered to be typical or average values in Thailand. A summary of the data is provided in Table 1.

The technical-economic data used for evaluation of wind technology is based on the use of Micon wind turbines M1500-600/150kW capable of generating in excess of a million kWh per year at mean wind speed of 6 m/s. Wind turbines used to provide electricity to grids worldwide currently range from 40kW to more than 2 MW [13]. The 6 m/s assumption was made since it is the minimum wind speed at which wind technology becomes technologically and economically possible for supplying power to the utility grid. The turbines are imported from Denmark and the exchange rate is set to 8.01 Baht per Dkk. The technical-economic data used for evaluation of solar technology is based on the implementation of 40 MW stand-alone solar power plants with batteries. Data for small-scale hydropower systems is taken from TDCSE [6] to represent typical technical-economic conditions for hydropower systems of a few MW. Data used for a typical industrial CHP plant is based on data from an existing high-pressure biomass CHP plant producing 2.5 MW of electricity from rice husk in Thailand [6, 14]. Finally, the data used to evaluate the coal-fired benchmark are from the 1,400 MW coal-fired power project under construction in Prachuap Khiri Khan, Thailand. The economic costs are calculated for each technology assuming an investment life of 20 years, and a discount rate of 10%. All investments are implemented over a two-year period starting in 2001, and energy production during the first year is 50% of total energy production. The two-year investment and retirement periods are originally for the coal-fired plant at Prachuab Khiri Khan. The same assumption was then made for other technologies to maintain consistency across technologies. Assumptions on fuel prices and escalation rates are reported in Table 2 and are identical to EGAT's assumptions. All results are calculated in units per kWh to provide a basis for comparison. Existing subsidies and taxes are not taken into account.

The third component of the model is an evaluation of the effect of each technology on the national economy. Contribution to GDP is calculated as the difference between total and imported discounted investment, O&M and fuel costs every year. To compute the national employment contribution, the

Table 1 Summary of Technical-Economic Data

Wind Technology (Based on Micon m1500 – 150 kW turbines)	
• Investment (million Baht/MW)	81.07
import share	0.75
• O&M (million Baht/MW)	2.83
import share	0.70
• Wind speed (m/s)	6.00
• Turbine production (MWh/year)	1102.50
Solar Technology (Based on 40 kW PV power plants)	
• Investment (million Baht/MW)	619.00
import share	0.86
• O&M (million Baht/MW)	1.24
import share	0.15
• Production (hours/year)	3600.00
Micro-hydro Technology	
• Investment (million Baht/MW)	900.00
import share	0.34
• O&M (million Baht/MW)	50.00
import share	0.15
• Production (hours/year)	6000.00
CHP technology (Based on a 2.5 MW rice husks CHP)	
• Investment (million Baht/MW)	50.00
import share	0.70
• O&M (million Baht/MW)	1.24
import share	0.15
• Production (hours/year)	6000.00
• CHP electric output (%)	20.00
• CHP thermal output (%)	60.00
• Boilers thermal output (%)	80.00
Coal-Fired Technology (Based on a 1400 MW power plant)	
• Investment (million Baht/MW)	33.43
import share	0.70
• O&M (million Baht/MW)	0.33
import share	0.15
• Production (hours/year)	6000.00
• Electric output efficiency (%)	44.77
Demand-Side Management Technologies	
• Investment (million Baht/MW)	28.00
import share	0.70

Table 2 Key Assumptions

General Assumptions			
• Investment life	20 years		
• Discount rate	10%		
• Exchange rate (Baht/US$)	39.00		
• Exchange rate (Baht/DKK)	4.87		
Assumptions – National Economic and Social Impact			
• Average salary (Baht/year)	91 800.00		
• Salary share of GDP	70.00%		
• Public revenue factor	19.45%		
Assumptions – Fuel Costs, Air Emissions	Coal	Biomass	Oil
• Price (Baht/MWh)	254.00	400.00	424.00
• Escalation rate (%)	2.08	0.00	1.42
• Import share (%)	90.00	20.00	90.00
• CO_2 emissions (kg/Gj)	95.00	-	74.00
• SO_2 emissions (kg/Gj)	0.40	0.13	0.141
• NO_x emissions (kg/Gj)	0.40	0.20	0.075
• Fuel in existing industrial boilers (%)	29%	34%	37%

salary share of GDP is estimated at 70% in Thailand, and the average salary is set at 91,800 bath per year (a little less than US$ 200 a month), based on salary information from the construction phase of the benchmark coal-fired power plant in Prachuap Khiri Khan, Thailand. Note that the calculations imply that people employed in a project would be otherwise unemployed. The contribution to public revenue is estimated at about 19.45% of the salary share of GDP as follows: average personal income tax is 2.25%; the value added tax is currently 7% and is applied to 90% of the total sum of salaries; and savings from social welfare payments to otherwise unemployed workers are estimated at 10.9% of the salary share of GDP based on a welfare payment of 10,000 baht/person/year.

The fourth component focuses on energy technologies' impact on rural development. Contribution to rural economy comes mainly from O&M costs of power plants located in rural areas. Hence, the non-imported share of O&M is used as a proxy for rural economy contribution. The same average salary of 91,800 baht per year is used to calculate the contribution in man-year/kWh.

The last component of the model is an evaluation of air emissions and externality costs. Air emission factors are from environmental impact assessment projects conducted in June 1999 by Sangsan, and are reported in Table 2. Methodologies used for external cost valuation vary widely from one study to another, resulting in very different values for identical fuel cycles. This is because most studies use different assumptions (such as Value of a Statistical Life (VSL) values) and consider a different number of externalities. One approach is to do an exhaustive review of the literature and calculate an average externality cost for each fuel cycle or energy technology [8]. However, this approach makes comparison across technologies less meaningful because the assumptions underlying the studies on which each average is based can be very different. Schleisner [15] provides an excellent literature review of externality valuation in the energy sector and explains that external costs can vary widely when the same methodology is used to evaluate the same technology but based on different projects or case studies. Indeed, a wind farm may have little environmental impact if located in a remote area but can have very substantial impact if located near inhabited areas with rare bird species and beautiful landscapes.

Thus, the authors prefer to use data from the PACE study [16], the only study that calculates environmental externality costs for all the technologies and fuels under investigation in this study. Ottinger, et al. [16] used a "top-down" approach to calculate the value of damages from air pollution. The study does not include damage due to global warming. An average inflation rate of 3.3%, and an exchange rate of 39 baht per US$ is used. Ottinger et al.'s [16] figures were also adjusted by multiplying externality costs estimates by the Thailand-per-capita-GDP-to-United-States-per-capita-GDP ratio to account, albeit imperfectly, for the likely difference in willingness (and ability) to pay to avoid environmental damages in the two countries [17]. This adjustment method has been used in several analyses like that of Pearce's [18]. Note that this procedure results in low estimates for external costs because of the low GDP of Thailand relative to that of the U.S. after the Asian crisis (at least 30% less than that before the Asian crisis, because of the devaluation of the Thai baht relative to the US dollar).

Two quantitative measures have been developed, in an attempt to summarize the results. A National Objectives Consistency Score (NOCS) is calculated for each technology as the weighted average of the GDPC-to-EC, PRC-to-EC, NEC-to-EC, and REC-to-EC ratios. The NOCS score can be loosely interpreted as how much, on average, each baht invested in a particular technology contributes to the national socio-economic objectives. The net socio-economic and environmental costs of each technology is also computed as the economic costs net of the potential for public revenue contribution and the externality costs from air pollution.

5. COMPARATIVE COST EFFICIENCY

5.1 Economic Costs (EC)

Wind, solar PV, micro and mini-hydro, industrial biomass CHP, and large-scale coal-fired technologies are compared. Conventional coal-fired technology is used as the benchmark technology since it has been selected (along with natural gas-fired) by Thailand as one of the main technologies to be used to replace and expand its power supply [19]. EGAT plans to generate 17% of its electricity using imported coal by 2011, from 0% currently.

The benchmark coal-fired technology is found to be significantly less expensive than alternative power supply technologies. The Industrial biomass CHP alternative has economic costs that are relatively competitive with those of the benchmark technology at 1.63 baht/kWh, about 20% higher than the benchmark. Increasing the lifetime from 20 years to 25 years or decreasing the discount rate from 10% to 7% also result in all alternative technologies becoming more competitive with the benchmark, but without changing the overall ranking of the technologies. This result highlights the existence of a sharp difference in cost structure between traditional and alternative technologies, where alternative technologies require large up-front investment but have low or no fuel costs while traditional technologies have low investment costs but large fuel costs.

Wind technology is found to have a cost of 3.18 Baht/kWh, more than twice the cost of the benchmark technology. In addition, this figure is obtained based on a mean wind speed of 6 m/s thus considerably reducing the applicability of this technology in Thailand. The output from the existing 150 kW turbine in Phuket, Thailand is 200 MWh/year under normal operation conditions. If this figure is used in the analysis instead of the one reported by the turbine manufacturer under mean wind speed of 6 m/s, the economic cost increase to 17.58 baht/kWh, making it only slightly less expensive than the average solar PV power plant. Both solar and small-scale hydropower systems appear not economically feasible at this time, with economic costs more than ten times that of the benchmark technology. The estimates for solar PV in this study are consistent with that of Samukkan, et al. [1]. In 1997, Samukkan, et al. [1] reported a cost of 17.08 Baht per kWh for a 1 MW grid connected PV system without storage in Thailand, assuming a 20 year lifetime and a 12% discount rate. They reported that cost estimates are strongly dependent on the cost of PV cells (exchange rate not provided) and the discount rate. They forecast a possible decrease of PV energy to 8.87 Baht/kWh at a discount rate of 8% if module prices decrease and efficiency increase by more than 20%.

5.2 Risk and Uncertainties

Because of the difference in cost structure discussed above, the financial risk associated with alternative systems is higher than that of coal-fired or other conventional technologies. Private investment in high pressure CHP system may already be economically feasible but is made difficult because of the need for significant up-front capital, a factor of production that many firms in Thailand currently lack as they slowly recover from the Asian crisis. In addition, the investment and O&M costs of industrial CHP systems are much more variable than that of large-scale conventional power plants because of variability in fuel characteristics (such as humidity), and the need to adapt the technology and the power plants to meet the need of each industry and the natural environment [15]. Investment costs in highly efficient industrial CHP plants can range from US$ 1,000 to US$ 1,650 per kW_{el}.

In terms of reliability of supply, the risk for major power failure is likely to be lower for alternative technologies because they imply the development of a decentralized energy production system. Some energy experts argue that Thailand lacks the experience for implementation of an efficient decentralized system and that some of the alternative technologies are not yet well proven, such as small hydro. In addition, the supply of electricity from solar, wind energy, and biomass CHP systems are typically seasonal and dependent on the natural elements, which further increase risk. The combination of traditional and alternative technologies is needed to insure reliable supply of power.

The estimates of costs do not specifically deal with issues of grid-connection and dispatching. However, experiences from Denmark and Finland suggest that purely technical difficulties are easily solved [13]. Also, it is important to note that decentralized energy production would result in potentially significant cost savings not included in the analysis, such as reduced transmission and distribution losses in the electricity grid.

6. EFFECTS ON THE NATIONAL ECONOMY

6.1 Import Content/Effect on the Balance of Payments

Import shares of investments and O&M can vary widely from one project to another, even when the same basic technology is used. The ones used in the analysis were determined based on a review of existing projects, feasibility studies, and expert interviews. For example, expert interviews in COGEN revealed that industrial CHP projects typically have a 70% import share on investment expenditures rather than the 50% reported by TDCSE [6]. COGEN is a consulting company specializing in feasibility and engineering studies of high-pressure biomass CHP in ASEAN.

High Pressure biomass CHP systems are found to have negative fuel import costs as (a) most of the biomass fuel is produced locally and (b) coal and oil used in existing industrial boilers to generate process heat (Table 2) are substituted by biomass used in high-pressure cogeneration plants. Hence, while the conventional coal-fired technology has the lowest capital and O&M import costs in Baht/kWh, it has very high fuel import costs which makes this technology less attractive than biomass CHP in terms of balance of payment but also because it creates dependency on foreign suppliers of coal - a strategic factor that certainly needs consideration.

Wind technology comes a close third in terms of economic import costs at 1.53 baht/kWh. Solar and small-hydro power technologies again come last with economic import costs about ten times higher than the benchmark technology.

6.2 Potential for Development of Innovative Industries

PV cells are currently imported from various sources in the world market and generally assembled into PV panels locally. Related hardware such as battery and charge controllers are also produced locally for small PV system. In this study, we focus on central power plants for which the share of imported components is likely to be greater than for small stand-alone system. Wind turbines are typically imported from Denmark or Finland, who have a strong competitive and technological advantage. Small hydropower turbines and systems are currently produced and imported from China. However, the Chinese technology is not well-proven and local expertise and manufacturing capabilities are developing in Thailand. Main components of highly efficient CHP plants are currently imported from Western countries but Ramboll [20] finds that the local boiler industry could rapidly take up the development of high-pressure boiler depending on government policy.

At this point, it is important to note that the import content of alternative technology projects would likely drop significantly if the power authorities of Thailand would commit to one or more of these technologies. Indeed, alternative power projects are small decentralized projects for which expertise and parts could be supplied locally and competitively by emerging industries. This is particularly true for industrial CHP and small hydro technology but perhaps less so for wind and solar energy where foreign manufacturers have already a strong technological advantage and where the most expensive components (such as solar cells and wind turbines) are easily standardized for mass production. Also, this would not be the case for large-scale power plants where foreign firms can take advantage of very significant economies of scale and provide attractive financing options to sell turn-key solutions.

6.3 Contribution to GDP (GDPC)

Small hydropower, solar, and wind technologies contribute much more to the GDP than other technologies because of their much higher investment costs. Investment in alternative technologies would thus be a way to boost, perhaps artificially, economic growth. Note that the contribution of the benchmark technology to GDP is about 80% lower than that of Industrial CHP and wind systems, mostly because of the coal being imported. The argument could be that less than 100% of the money spent on power projects contributes to GDP because of transfer across sectors. However, the relative contribution of each technology would not change.

6.4 Contribution to Employment (NEC)

Small hydro technology contributes the most to employment in absolute term, but industrial CHP seem to be the most efficient way to generate employment, with a NEC-to-EC ratio of 0.68. The conventional technology contributes the least to employment both in absolute and relative term with an NEC-to-EC ratio of 0.16.

6.5 Contribution to Public Revenue (PRC)

Alternative technologies contribute from 400% (Industrial CHP) to 3700% (Small-hydro) more to public revenue than the benchmark technology on a per kWh basis. This is an important finding that indicates that alternative technologies may deserve substantial financial support from the government. The industrial CHP systems contribute only 0.3 Baht/kWh to public revenue but this is still about 0.294 Baht/kWh more than coal-fired technology. A government subsidy of this amount would put the economic costs of industrial CHP at par with those of large-scale conventional coal-fired power plants. Contribution to public revenues alone for wind, solar and small-hydro power technologies are not enough to offset their large economic costs.

7. CONTRIBUTION TO RURAL DEVELOPMENT

7.1 Economic and Employment Contribution (REC)

With a contribution of more than 7 baht/kWh to the rural economy and the second highest REC-to-EC ratio after industrial CHP, micro-hydro may be effective at reducing current unemployment in rural Thailand. A REC-to-EC ratio of 0.02 baht/kWh makes solar PV technology a low direct contributor to rural economy employment. The technology most beneficial to the rural economy is industrial biomass CHP with a rural employment contribution of almost 11 man years/GWh, far above that of the benchmark technology at 0.5 man years/GWh. Note that purchase of biomass fuels (priced at 400 Baht/ton in our analysis) is not considered a contribution to the rural economy. However, biomass fuels for industrial CHP projects are produced in rural areas and including them in the analysis would further increase the attractiveness of this technology relative to the benchmark.

7.2 Other Considerations

Implementation of alternative energy projects on a significant scale in Thailand would imply the development of a decentralized electricity production system, so that the socio-economic benefits (and burdens) from investment in additional electricity generation capacity would be shared more equally across the nation. The socio-economic benefits to rural areas from the decentralization of power production may not be fully accounted for in our CRE measure.

8. ENVIRONMENTAL AND HEALTH IMPACTS

8.1 Externality Costs from Air Pollution

One of the major benefits of alternative energy technologies is their low environmental impact and, more specifically, low air emissions. Indeed, the implementation of Industrial CHP results in negative atmospheric emissions as coal and oil used in existing industrial boilers is substituted with biomass used in high-pressure industrial cogeneration plants. The other alternative technologies do not produce air emissions directly. These technologies do generate indirect air emissions during construction of power plants, manufacturing of the parts, and eventual transportation of fuel.

Average externality costs per kWh are also reported in Table 3. Note that the externality cost for biomass reported is for an average biomass-based power project and not for an average industrial CHP project for which externality costs are expected to be much lower due to negative air emissions. The results show that conventional coal-fired technology would result in about 0.4 Baht/kWh of additional environmental damage as compared to alternative technologies. Taking this estimate into account when evaluating energy technology makes industrial CHP a very attractive alternative as compared with the authors' benchmark. Note that taking into consideration global warming and the cost of CO_2 would further increase the externality cost of the coal-fired technology by about 0.09 Baht/kWh [8]. Ottinger, et al.'s [16] study has been criticized because of its high externality cost estimates relative to more recent studies that rely on a damage function approach [21]. Thus, environmental damages from conventional coal-fired was also calculated based on the estimate from the more recent "bottom-up" externalities of energy study [22] and a similar value of 0.39 Baht/kWh was found. Tol [23] also studied the estimates of the marginal costs of greenhouse gas emissions.

8.2 Other Environmental Effects

Other environmental effects include noise, visual damage, and probability of injuring or killing humans or wildlife during operations. These costs are likely to be small for all energy technologies if locations are selected carefully. Wind farms are certainly at a disadvantage, and solar PV power plants are certainly at an advantage, relative to other energy technologies when these other environmental effects are considered.

Table 3 Summary of the Results

	Wind	Solar	Small hydro	Ind. Bio. CHP	Coal
Economic Costs (EC)					
Capital costs (Baht/kWh)	2.40	18.35	16.02	0.89	0.59
O&M costs (Baht/kWh)	0.78	0.34	8.33	0.25	0.06
Fuel costs (Baht/kWh)	0.00	0.00	0.00	0.50	0.67
Economic costs (Baht/kWh)	3.19	18.70	24.35	1.64	1.32
Economic Import Costs (EIC)					
Capital costs (Baht/kWh)	1.42	10.31	11.05	0.61	0.42
O&M costs (Baht/kWh)	0.12	0.05	1.25	0.04	0.01
Fuel costs (Baht/kWh)	0.00	0.00	0.00	-0.60	0.61
Economic import costs (Baht/kWh)	1.53	10.36	12.30	0.06	1.03
GDP Contribution (GDPC)					
Capital costs (Baht/kWh)	0.99	8.04	4.97	0.28	0.18
O&M costs (Baht/kWh)	0.67	0.29	7.08	0.21	0.05
Fuel costs (Baht/kWh)	0.00	0.00	0.00	1.09	0.07
GDP contribution (Baht/kWh)	1.65	8.34	12.05	1.58	0.29
GDPC to EC ratio	0.52	0.45	0.49	0.96	0.22
National Employment (NEC)					
Employment (man years/GWh)	12.62	63.57	91.91	12.06	2.24
Employment (Baht/kWh)	1.16	5.84	8.44	1.11	0.21
NEC to EC ratio	0.36	0.31	0.35	0.68	0.16
Public Revenue (PRC)					
Public income contribution (Baht/kWh)	0.32	1.62	2.34	0.31	0.06
PRC to EC ratio	0.10	0.09	0.10	0.19	0.05
Rural Economy (REC)					
RE contribution (Baht/kWh)	0.23	0.29	7.08	1.20	0.05
RE employment (man years/GWh)	5.98	2.62	63.54	10.75	0.42
REC to EC ratio	0.07	0.02	0.29	0.73	0.04
Environmental Effects					
CO_2 emission (000 kg/GWh)	0.00	0.00	0.00	-1832.55	763.90
SO_2 emission (000 kg/GWh)	0.00	0.00	0.00	-5.61	2.98
NO_x emission (000 kg/GWh)	0.00	0.00	0.00	-4.80	1.53
Externality costs (Baht/kWh)	0.01	0.02		0.04 *	0.42
Net Socio-Economic and Environmental Costs (Baht/kWh)	2.88	17.10	22.01	1.37	1.68
Socio-Economic Impact Score	0.26	0.22	0.31	0.64	0.12

* This estimate is for all biomass energy projects rather than for high efficiency industrial CHP.

9. HOLISTIC INDICES OF ENERGY TECHNOLOGIES IN THAILAND

The NOCS scores suggest that 0.22 of every Baht spent on an average solar PV power plant during its 20 years of operation contribute directly to the broader national objectives listed in the introduction. The NOCS score shows that industrial CHP and small-hydro power technologies are the most consistent with national objectives, followed by wind, solar, and traditional large-scale coal fired technology.

The net socio-economic and environmental cost estimates indicate that industrial CHP has a net cost of 1.37 Baht/kWh, as compared to 1.68 Baht/kWh for the benchmark conventional technology. Our holistic analysis suggests that industrial CHP remains cheaper than conventional coal even when externality costs from air emissions are not included in the calculations. The other three alternative technologies have much higher net cost at this time.

10. CONCLUSION

This report presented a holistic approach to energy technology evaluation, in an attempt to strike a balance between national socio-economic objectives and the narrower objective of minimizing the investment and O&M costs of power projects. While the approach was specifically applied to the case of Thailand, many of the results can be generalized to neighboring ASEAN countries. In addition, the methodology presented in this paper can be readily used to evaluate energy technologies in countries with similar national objectives.

This comparative analysis showed that conventional coal-fired technology is indeed the least-cost energy supply technology when socio-economic and environmental impacts on the Thai economy are not considered. It also showed that alternative technologies can contribute more to GDP, national employment, public revenue and rural development than traditional large-scale coal fired power plants, while at the same time reducing the impact on the environment and human health and reducing dependence on foreign fuel.

The results reveal that industrial biomass cogeneration and small hydropower technologies are most consistent with broader national objectives, followed by wind, solar PV, and conventional coal-fired technologies, in this order. However, economic costs of small hydro and solar technologies remain prohibitive at this time. The applicability of wind technology is dependent on finding locations in Thailand where average wind speeds equal 6 m/s, which may only be found offshore. Industrial CHP ranks second in terms of economic costs (1.63 Baht/kWh), but first in terms of consistency with national objectives and net socio-economic and environmental cost.

The study indicates that Thailand would, on average, benefit more from the development of grid-connected CHP projects, than from implementation of large-scale turn-key coal-fired power plants. In fact, public revenue from industrial CHP projects is expected to be 0.31 Baht/kWh versus only 0.06 Baht/kWh for conventional coal-fired projects. Hence, Thailand could afford to subsidize industrial CHP projects to help investors cover the large up-front investment necessary to build a biomass cogeneration plant.

Small hydro-power has been mostly ignored relative to solar and even wind technology. However, support of micro or mini hydropower demonstration projects is suggested because of its potentially significant contribution to national employment and rural development, and the fact that Thailand could develop local expertise and manufacturing capabilities to supply national and international markets. While the potential for solar energy is enormous in Thailand, the contribution of solar technology to national objective is low and economic costs remain prohibitive. Investment in solar PV power plants is not justifiable at this time.

The current plan for expansion of the electricity generation capacity of Thailand includes mostly natural-gas fired and coal-fired power projects. Substituting some of the large scale coal-fired power plants by a decentralized network of grid-connected high-efficiency biomass CHP plants in cooperation with the agro-food industries in Thailand would be both cheaper and more consistent with national objectives. Given an existing structural potential of 3000 MW, development of 1500 MW of electrical power from industrial CHP within the next decade is a challenging but reasonable target that represents 9.7% of the 1998 installed capacity [24].

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