PNWD-3123

Taiwan Electric Power Futures

William Chandler

December 2001

Advanced International Studies Unit

Pacific Northwest National Laboratory

Acknowledgments

The author would like to express gratitude to the following persons for their leadership, assistance, and reviews: ZHANG Ji-Qiang of the W. Alton Jones Foundation; WANG To-Far of the National Taipei University; Richard HSU, WANG Hui-Sheng, and LIN Jeng-Yih of the Taiwan Power Company (Taipower); Barbara FINAMORE of the Natural Resources Defense Council; Holly GWIN, HSU Kuang-Jung of the Taiwan Environmental Protection Union; John BYRNE of the University of Delaware; and Jeffrey LOGAN, Thomas SECREST, Meredydd EVANS, Karen KING, and Paulette WRIGHT of Battelle Memorial Institute's Pacific Northwest National Laboratory.

The author would like to express special thanks to the president of Taipower, C.C. LIN, for his hospitality in Taipei in organizing a special presentation of this report on 23 November 2001 to the Taipower board of directors, senior staff, and invited environmentalists. This version of the report has been revised in response to the questions and comments posed in that forum.

TAIWAN ELECTRIC POWER FUTURES

Battelle Memorial Institute, Pacific Northwest National Laboratory

Abstract

This study assesses Taiwan's options for meeting future electric power demand while satisfying civic and economic objectives. It is intended to support policy makers, business leaders, researchers, and environmentalists in their efforts to enhance Taiwan's economy, environment, and security.

The study quantifies the economic and environmental costs of alternative means for meeting projected electric power demand through 2020, and makes policy recommendations to minimize these costs. Key focal points for policy makers include three areas: demand management, market reform, and technological development.

Introduction

The objective of this study is to assess Taiwan's options for meeting future electric power demand while satisfying civic and economic objectives. This study's purpose is to clarify the implications of electricity supply choices, and thus to help reduce the uncertainty and conflict affecting Taiwan's power supply system. The results may help policy makers, business leaders, researchers, and constituents enhance Taiwan's, economy, environment, and security.

This study is a collaborative effort of Battelle Memorial Institute's Pacific Northwest National Laboratory (Battelle), the Taiwan Power Company (Taipower), and the Natural Resources Defense Council (NRDC). Battelle and NRDC's participation has been funded by the W. Alton Jones Foundation, while Taipower's participation was funded internally by that company. While Battelle has taken the lead in performing this analysis and takes responsibility for it, NRDC provided leadership to initiate the study, and Taipower provided extensive knowledge and data about the electric power system. External specialists, including Taiwanese and American economists, environmentalists, electric power experts, and policy specialists, have commented on earlier drafts.

The author assesses Taiwan's electric power future by quantifying the economic and environmental costs of alternative means for meeting projected electric power demand through 2020. The study applies scenario analysis using a linear programming model to create plausible visions of Taiwan's electric power future. These futures include a baseline, which is based on a *status quo* assessment performed in March 2001 by Taipower, and a modified base case, which applies lower GDP growth assumptions suggested in a September 2001 Taipower study. The modified base case further assumes that some of the older nuclear power units will be retired early for policy reasons. Two sets of variations have been built on these two base cases, including an energy sector reform case, in which restructuring of both gas and electric power supply markets make gas more competitive, an efficiency case, which explores the potential for cutting power demand, and a low carbon dioxide emissions

case, in which carbon dioxide is relatively strictly controlled. The cases are generally supplemental, with successive cases building on the previous ones. For example, the efficiency case incorporates the assumptions of energy sector restructuring and nuclear retirements of the prior energy sector reform and base case scenarios. In addition, there is an efficiency scenario built on the lower GDP assumptions of the modified base case.[1]

Credibility in any modeling exercise stems from transparency of assumptions made, validity of the economic tools applied, and reproducibility of the results reported. To enhance the credibility of this exercise, all important assumptions are presented in the main report. The assumptions and model have been reviewed by a diverse review panel. Participants and reviewers in this study include experts with a range of views on environmental, climate, and nuclear power issues, but the author assumes full responsibility for the contents of this report.

The Current Context

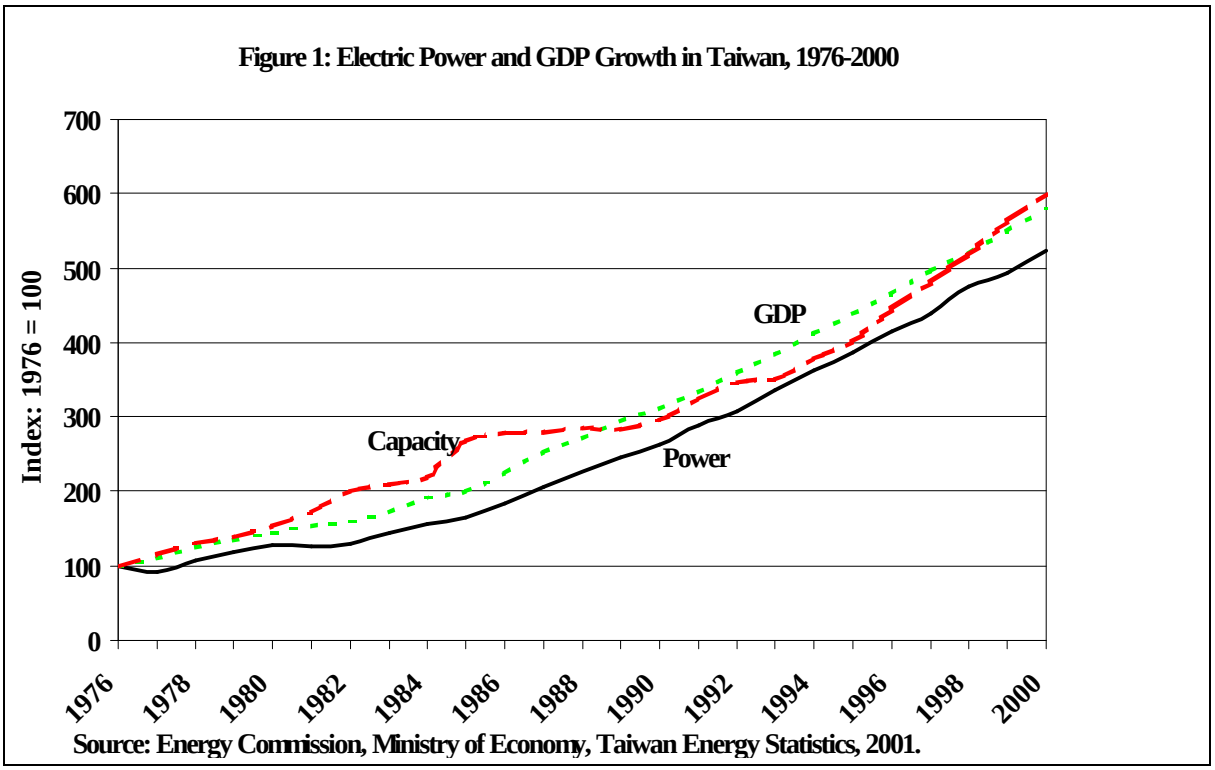
Power Demand and Supply

Projected electric power demand–the demand forecast–overwhelms in importance almost all other considerations of Taiwan's electric power options. The recent economic downturn has led to a dramatic downward shift in some power demand projections. For example, power generating capacity requirements projected for year 2015 dropped approximately 9,000 megawatts between Taipower's March and September year 2001 forecasts.[2] This shift in thinking stems almost entirely from reduced economic growth forecasts for the period. Consequently, a new approach to power demand management may be warranted to reduce the risks of either over-building or under-building electric power plants. Such an approach would necessarily require policy measures by agencies and actors beyond the direct control–but possibly not the influence–of the Taipower board of directors.

1. The linear-programming model used in this analysis was developed by Jeffrey Logan at the Pacific Northwest National Laboratory, and has been applied in studies of Argentina, Brazil, China, India, and the Republic of Korea. See www.pnl.gov/aisu.

2. The economic downturn appeared to worsen when the world economy was shocked by a terrorist attack on the United States on 11 September 2001. See, for example, "Typhoon, Attack on US Cut GDP Forecast Further Back," *Taipei Times*, 22 September 2001, online edition, www.taipeitimes.com/news/2001/09/22/. The lowered demand forecast by Taipower was provided in a private communication by the Taipower Office of Power Planning, 10 September 2001.

Taiwan uses energy and electric power intensively. The economy's energy intensity, defined as



energy consumed per unit of economic output, is comparable to that of the United States.[3] Electric energy intensity is also high. These high levels stem from Taiwan's advanced level of economic development, reliance on heavy industry, widespread use of air conditioning due to the island's semi-tropical climate, and price and other economic distortions in the economy and the energy sector.

Economic output in Taiwan has reached roughly US$13,000 of GDP per capita, placing it on a par with European countries like Greece, Portugal, and Spain. Energy consumption, at 155 gigajoules (GJ) per capita, is close to the average per capita energy use in Western Europe.[4] Taiwan's electric power demand, at almost 7,900 kWh per person per year, is higher than in Germany and almost two-thirds that in the United States.[5] Power demand in Taiwan is dominated by industry, which uses two-

3. Ministry of Economic Affairs, *Taiwan Energy Statistics, 1999* (Taipei, Republic of China), September 2000.

4. Energy data from Energy Commission, Ministry of Economic Affairs, *Taiwan Energy Statistics, 2000*, Republic of China, April 2001. Converted from liters of oil equivalent at 9000 kilocalories per liter and 4,186 Joules per kilocalorie. See also, U.S. Energy Information Administration, "Taiwan Energy Brief," November 2001, www.eia.doe.gov. Data converted from British Thermal Units (BTU) at 1,055 Joules per BTU.

5. The exact figure for 2000 is 7,772 kilowatt hours per capita. Source: Energy Commission, Ministry of Economic Affairs, *Taiwan Energy Statistics, 2000*, Republic of China, April 2001. See also, U.S. Energy Information Administration, www.eia.doe.gov, May 2001.

thirds of all electricity generated on the island (see Table 1). Residential demand accounts for most of the remaining consumption.

Table 1: Taiwan Sectoral Power Use, 2000
Terawatt-hours (TWh)

	TWh	Percent
Industry	94.8	67
Residential	34.7	24
Commercial	12.9	9
Total	142.4	100

Source: Taiwan Energy Commission, Ministry of Economic Affairs, *The Energy Situation in Taiwan*, 2001.

Power demand has grown rapidly over the past quarter-century in Taiwan, more or less in lock-step with the economy (see Figure 1). Installed capacity reached 38,334 megawatts in 2000, 77 percent of which was owned by Taipower. Power generating capacity in Taiwan is diversified among the conventional sources of coal, nuclear, oil, and liquified natural gas (LNG). Coal accounts for about two-fifths and nuclear slightly more than one-fifth of total generation (see Table 2). Most coal, all liquified natural gas, and all oil fuels are imported. Domestically produced natural gas contributes about 13 percent of the total natural gas supply on the island, but is used minimally for power generation.[6] Dependence on foreign sources of energy is a major security concern for Taiwan, and security issues play a major role in the selection of capacity type and fuel sources. Power supply diversification has been a major goal, stemming from experience during the oil shocks of the 1970s. Taipower has consciously diversified its sources of power, and has implemented rules governing the share of fuel that may be acquired from any one country, and other rules that require stockpiling of interruptible fuel sources, including coal and LNG. For example, Taipower must stockpile 2 months of coal and 45 days of oil supply. Some Taipower experts believe that nuclear power enhances the island's energy security because a utility can operate a nuclear plant for one-and-a-half years between refuelings. Some experts, however, have cited security and environmental liabilities of nuclear power stemming from the risk of diversion of fissile material contained in nuclear fuel, and the direct threat posed by the possibility of a nuclear accident or terrorist act.[7]

A "National Energy Conference" in 1998 set policy goals for national electricity capacity mix. The goals for power *capacity*, or watts, by fuel type were recommended to be in the range of 35-37 percent for coal, 4-5 percent for oil, 27-29 percent for gas, 9-11 percent for hydroelectric power, 19-20 percent for nuclear, and 1-3 percent for "new energy." Taipower until now has considered LNG as a fuel best-suited to provide intermediate-load capacity, but if LNG comes to be used for base load

6. *Taiwan Energy Statistics, 2001*. See pp. 217, 221.

7. Hal Feiveson, Princeton University, "The International-Security and Greenhouse Implications of Nuclear Power in Taiwan," Proceedings, "International Conference on Sustainable Energy and Environmental Strategies: Taiwan and the World," 29-30 September 2000, Taipei, Taiwan (co-sponsored by the Center for Energy and Environmental Policy, University of Delaware, and the Institute for National Policy Research of Taiwan). Feiveson described impacts of a hypothetical ten-fold nuclear power expansion. See also, Wang To-Far, "Is Nuclear Power Really the Cheapest," *Taiwan News Opinion* (translated by Linda Gail Arrigo) 7 May 2000.

generation, fuel security may become an issue. Of growing importance is concern about global warming and the prospect that Taiwan could become even more dependent on coal, which produces more carbon dioxide per unit of energy released than any other major fuel.

Power Supply Structure

Demand and supply choices are strongly affected by the political and economic structure of the Taiwan energy industry. Taipower Corporation controls all power transmission and distribution in Taiwan and most, but not all, power generation. Independent Power Producers (IPPs) supply electricity to the grid on a negotiated "avoided cost" basis, in a policy somewhat resembling that of the U.S. Public Utilities Regulatory Policies Act (PURPA).[8] IPPs currently control 2,250 megawatts of generating capacity, and cogenerators own an additional 5,138 megawatts of generating capacity.[9] Taipower encourages IPPs to build new capacity in the power-short north because of a limitation in the ability to transmit additional power to the northern section of the island. The IPPs and cogenerators together control over one-fifth of power generating capacity on Taiwan. Cogenerators have the advantage of being able to sell cogenerated power to Taipower–to the grid–at any time, regardless of system power needs. The rate paid to cogenerators for the first 20 percent of their capacity equal the rate charged to industrial customers. That is, the rates paid not only reflect Taipower's avoided cost of generation but also transmission and distribution costs. For the remaining 80 percent, delivery costs are subtracted from the rate paid.

Table 2: Taiwan Power Generation by Type, 2000

Source	Percent
Coal	39
Nuclear	24
Oil	16
LNG	10
Hydro	6
Cogeneration	5

Source: Taiwan Power Corporation, 2001. Note: Percentages are shares of total kilowatt-hours generated. Note further that cogeneration plants are fueled by coal, LNG, and oil.

Power sector restructuring has been a slow process, but has included an evolving effort to privatize Taipower Company and to create competition in power generation and sales. Less than 6 percent of shares in Taipower are now held by private owners, and management and power supply policy remain government controlled.[10] Further auctioning of Taipower shares has been postponed, possibly for

8. The policy in Taiwan differs from PURPA rules in that the "avoided cost" paid to "qualifying facilities" differs as a function of fuel type, with one price paid to producers using coal and a different price for generators using other fuels such as LNG and oil.

9. Cogeneration, in this context, means combined heat and power production, for on-site consumption. Taiwan rules define a qualifying cogenerator as one with a–relatively low–efficiency just above 50 percent for power and steam generation.

10. The Taiwan Central Government owns 94.04 percent of the Taiwan Power Company, with 5.96 percent owned by institutional and individual investors. Source: Power Development Department, "Long Range Power Development Program, 2001-2010," Taiwan Power Company, February 2001.

several years. Though more than a half-dozen power sector restructuring bills were introduced in the parliament by mid-2001, action on the issue was affected by parliamentary elections in late 2001.

A study such as this must deal explicitly with technology choice, in particular the controversy over nuclear power. The news media have detailed that controversy in Taiwan, which has centered on completion of the "Fourth Nuclear Power Plant." The plant's two reactors, originally scheduled for completion by 2005, would provide 1,350 megawatts each. In October 2000, President Chen Shui-Bian announced that his administration would cancel the plant, a position consistent with his campaign promises and the policy of his Democratic Progressive Party (DPP). But in early 2001, the Taiwan parliament, which was then led by the opposition party, or Kuomintang (KMT), voted that the Taiwan administration restart construction of the nuclear plant. That vote followed a January ruling by the Council of Grand Justices–the "supreme court" of Taiwan–which concluded that the government had erred by canceling the plant without consulting the parliament. Consequently, the administration agreed to allow construction on the Fourth Nuclear Plant to continue. At the time of this writing, it is widely assumed in Taiwan that the Fourth Nuclear Plant will, in fact, be completed, but at an increased cost of perhaps US$100 million due to interest charges and contractor penalties. It is unlikely that the government of Taiwan will finance any new nuclear capacity additions, though it is possible that a privatized Taipower Corporation could do so. At the same time, it is possible, even likely, that some of the older nuclear power plants in Taiwan might be retired early in response to concerns about nuclear safety, nuclear waste, and proliferation of weapons-usable material. Each of these possibilities contributes to the uncertainty of Taiwan's electric power future.

Power Pricing and System Management

Heavy air conditioning demand makes Taipower a summer peaking utility, and sometimes strains the supply system. The Taipower summer peak in the year 2000 reached 25,854 megawatts in a system with approximately 30,000 megawatts of net peaking capability. The reserve margin–the percentage by which installed capacity exceeds annual peak load–has varied from 9 to14 percent over the past five years. Most power planners would prefer to have a reserve margin approaching 20 percent, although Taiwan has experienced nothing like the capacity shortages seen in California in recent years. The year 2000 summer peak averaged 7,000 megawatts more than the winter peak that same year (see Table 3).[11]

Several Taipower programs exist for peak-shaving, including "time-of- use" rates, interruptible industrial rates, devices which cycle air conditioners on a scheduled basis, and devices which cycle air conditioners on a "paging" basis. Information, education, and outreach efforts encourage peak-shaving behavior among "lighting" customers, including small restaurants and hotels. Seven

11. Wang Hui-Sheng, Taipower, private communication at Battelle, Pacific Northwest National Laboratory, Washington, D.C., May 2001.

Table 3: Taipower Net Peaking Capability, Average Power Demand, and Peak Demand, 1996-2000 (gigawatts; percent)

	Installed Capacity (A)	January Peak (B)	July Peak (C)	B/C	C/A
1996	23.8	14.7	21.8	67%	92%
1997	25.7	16.1	22.2	73%	86%
1998	26.7	17.3	23.8	73%	89%
1999	28.5	17.9	24.2	74%	85%
2000	29.6	18.9	25.8	73%	87%

Source: Taiwan Power Company, 2001.

categories of interruptible power rates are offered as incentives to reduce peak demand, especially in summer. Electric power tariffs in Taiwan vary by service voltage, time of year, and time of day.[12] The Taipower rate schedule in effect in 2001 established residential rates ranging from NT$2.0 to NT$3.3 for non-summer and summer rates, or US$0.070-0.106 per kilowatt hour.[13] Residential rates vary by level of demand with higher rates applied to consumption over 330 kilowatt hours per month and the lowest rates applied for the first 110 kilowatt hours consumed per month. Commercial "lighting" customers–Taipower uses the term "lighting" to define non-industrial customers–were charged US$0.083 and US$0.106 for non-summer and summer power usage, respectively. Peak rates vary for high tension, or industrial, customers depending on contractual terms that define peak hours. For example, the rate for summer usage during normal daytime working hours is US$0.062 per kilowatt hour. The off-peak, non-summer rate for customers selecting that contract, however, is only US$0.022. Another option is the so-called "mobile" peak rate of US$0.17 per kilowatt for very high peak times. But customers choosing the mobile peak rate–which Taipower designates depending on its needs, after notification of the customers–otherwise purchase power in summer and winter for as little as $0.02 per kilowatt hour (for selected rates, see Appendix 1). It should be noted that industrial customers also pay a monthly connection charge, which ranges from US$5.09 to 6.82 per kilowatt of power in non-summer and summer periods, respectively.[14]

Time of use pricing helped reduce peak demand in 2000 by almost 3,200 megawatts, according to Taipower, thus helping to balance power supply and demand and to avoid costly capacity additions.[15]

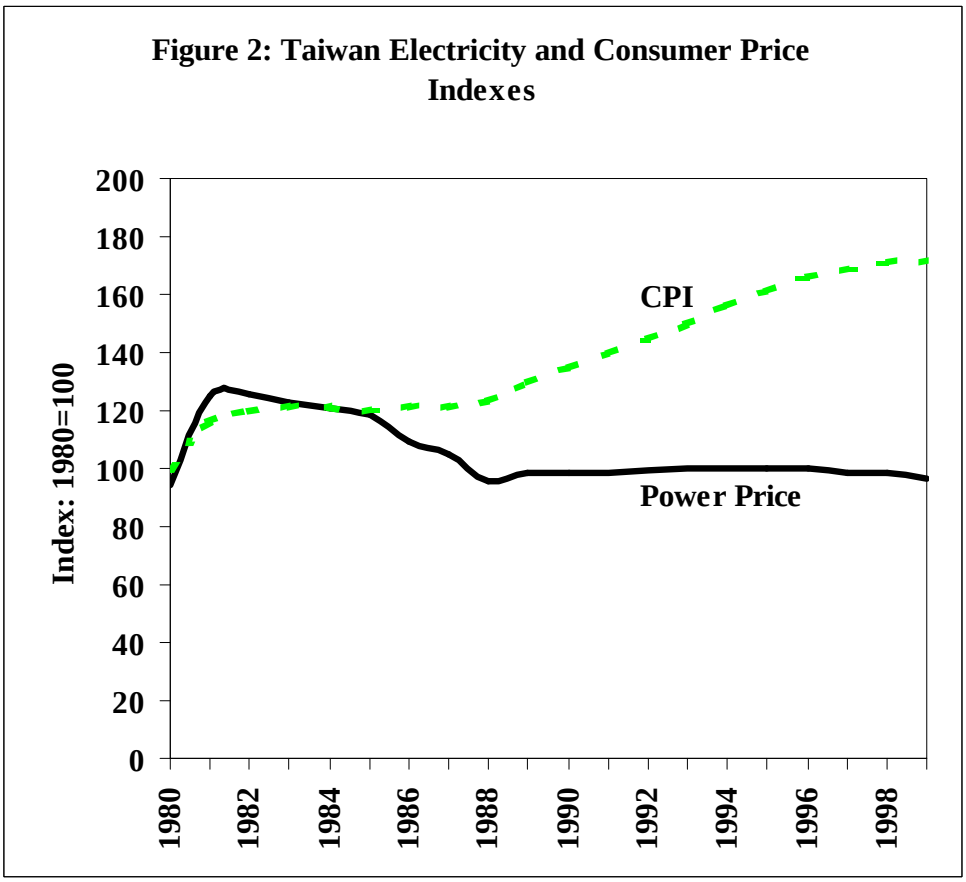
---

12. The structure of electric power rates in Taiwan can be illustrated by taking one notional rate, a mid-2001, off-peak power rate of NT$1.8771 per kWh, and allocating the cost to its principal components. These components include generation, transmission, distribution, "other," and interest charges which amount to 65, 6, 14, 3, and 7 percent of the total rate charge, respectively. Source: Taipower, May 2001.

13. This conversion was made using a first-half 2001 exchange rate of NT$31.23 per U.S. dollar. The value of the new Taiwan dollar (NT$), however, declined to 34.5 per U.S. dollar by the end of August 2001.

14. Industrial customers must pay a "demand" charge per kW per month and an "energy" charge per kWh. Those rates in 1999 ranged from NT$153-207 per kW for "regular contracted demand", and 1.88-1.95 per kWh for non-summer and summer peak consumption and 0.70-0.76 for off-peak contracted demand in the same category. Source: "Taiwan Power Company Rate Schedules, Taipower Corporation, Taipei, Taiwan, 2001.

15. See, for example, Wang Hui-Sheng, Deputy Director, Power Development Department, Taiwan Power Company, "Outlook of [the] Power System in Taiwan," in Science and Technology Advisory Group, Executive



An off-peak price of US$0.02 exceeds the variable cost of coal-fired production by 20 percent, but amounts to only 60 percent of the full cost–fuel, plus O & M, plus capital–of coal-fired power. Thus, off-peak prices may actually be below cost of service. Indeed, Taipower now earns a return on investment of only about 6 percent. Formerly, the Legislative Yuan, or parliament, agreed that Taipower should earn a rate of return between 9.5 and 12 percent, but the lower level has not been met for many years.[16] Taipower experts point out that power prices have declined in real terms (see Figure 2). This fact may indicate a significant subsidy for electric power consumption through the rate-making process.[17] Indeed, the average prices for buildings (again, defined as "lighting") and industrial customers in 1999 were, respectively, US$0.08 and US$0.06. The average of these two categories amounts to only US$ 0.0675, well below the cost of intermediate load (LNG-fired) power generation–even excluding transmission and distribution costs.[18] The conclusion that can be drawn from these figures

---

Yuan, and Energy Commission, Ministry of Economic Affairs, *Energy Technology and Innovation Workshop*, July 30 to August 3, 2001, Taipei, Taiwan. This paper offers an excellent overview of the Taiwan electric power situation.

16. See "Annual Report, 2000," Taipower Company, Taipei, Taiwan, 2001.

17. This situation has financial as well as economic and environmental implications. Taipower maintains its AAA bond rating, but some observers fear that the erosion in the value of power tariffs threatens that standing.

18. The source of the "average" prices is the Taiwan Power Company, as cited in "Historical Electricity Prices by Year," in Energy Commission, Ministry of Economic Affairs, *Taiwan Energy Statistics, 1999* (Taipei: Republic of China) September 2000. The comparison is made using calculations of the levelized cost of electric power from coal and LNG which we estimate cost US$0.04 and US$0.07 per kWh, respectively. The

that power use is subsidized and therefore artificially encouraged.

Fuel supply, especially that of LNG, is also heavily affected by state ownership and control. LNG is generally twice as expensive in Taiwan as on the world market, possibly because of a near-monopoly granted to the China Petroleum Corporation. Independent suppliers of LNG have recently been allowed to compete, but few market actors have come forward to bid on Taipower solicitations. Consequently, the price of natural gas is expected to remain unusually high and artificially inflated. Taipower estimates the future price of gas by taking a ratio of the relatively high price it is charged by the China Petroleum Corporation as a baseline and extrapolates that level at the same rate of increase assumed in world oil prices. One conclusion that can be drawn from this comparison is that relatively clean-burning LNG is discouraged by official policy in Taiwan.

Regional Issues

High-voltage transmission ranks high among the problems of providing power in Taiwan. Taipower assesses transmission system investment requirements by taking demand results from its econometric models and determining the size, location, and numbers of transmission facilities required. Results are reported as a matter of line length or voltage. The utility estimates that an investment of NT$450 billion (over US$14 billion) is required to construct and upgrade transmission facilities over the next five years. This figure does not include acquisition of rights-of-way. Local opposition to new power line construction is often strong and sometimes involves local governments in addition to citizen groups. It stems from concern for aesthetic impact and possible human health effects of exposure to high-voltage magnetic fields.

Taiwan is divided into three power management regions: North, Central, and South. The North region consumes just under one-half of the island's electric power, but accounts for only one-quarter of its generating capacity. The controversial Nuclear Plant No. 4 is planned for the North, and is comparable in size to the generating deficit in that area.[19] Other, non-nuclear generating plants have been canceled in some areas due to siting problems, with citizens near the proposed plants objecting to coal- and oil-fired options. Natural gas distribution, unfortunately, is limited around the island. The result is an imbalance between supply and demand in the three regions that threatens to make the grid unstable, a problem exacerbated by the difficulty of constructing high-voltage transmission lines. Construction of a 345 kilovolt line to the North region will be completed in 2002 and may help alleviate the power imbalance there. Zoning certain areas to encourage or discourage industrial

---

assumptions behind these calculations are provided in detail in the modeling section later in this report. Note that these cost estimates do not include environmental costs, which may drive coal's cost per kWh to US$0.06 or more. The Energy Commission currently allows only a 6.64 percent return on capital. Taipower's accounting department has recommended that management request a rate increase of 12.79 percent increase by 2003 and a total of 37.25 percent by 2020. Strikingly, Taipower is assuming a rate of inflation of zero during the 2003-2007 period, increasing only to 1and 2 percent, respectively, in the 2008-2012 and 2013-2020 periods. Source: Private communication, Taipower, Taipei, 24 August 2001.

19. Nuclear plant number 4 would have two units generating a total of 2,700 megawatts. The units were projected in early Summer 2001 by Taipower to be operational in 2005 and 2006.

development has been suggested as an alternative approach to regional power imbalances, but this action would involve a compromise of diverse interests across the entire political and economic spectrum.

Implications

The current context of power demand and supply in Taiwan includes a number of competing objectives and interests, and a legacy of both success and conflict. While the electricity supply system in Taiwan has powered remarkable economic development, imbalances have arisen which threaten the economic security and environmental aspirations of segments of the population. The state-owned nature of the electric power sector has complicated these matters because power planning has become a focal point for larger issues. Consequently, an exploration of electric power futures for Taiwan must include considerations of economic restructuring and environmental protection along with more prosaic issues of power engineering.[20]

Projecting Taiwan's Electric Power Future

This section evaluates the economic, environmental, and policy implications of Taiwan's electric power future in plausible scenarios of technology choices. The scenarios start with actual conditions in the year 2000 and run, in five year increments, to the year 2020. The methodology applied here comprises levelized cost analysis, linear programming, and analysis of key future variables, including rates of economic growth, capital and fuels costs for various energy alternatives, and environmental policies.[21] Eight scenarios have been drawn, four utilizing high and four utilizing low economic growth assumptions.[22] First, a *baseline* scenario incorporates the assumptions of Taipower's experts. Second, a *modified baseline* scenario repeats the baseline case, but is based on lower economic demand growth. This scenario also incorporates the early retirement of older nuclear power plants. Third, an *energy sector reform* scenario mimics technology decision-making that could result from market-based restructuring of the utility and fuel supply sectors in Taiwan. This projection uses the higher economic growth rates of the baseline case, but assumes lower LNG prices stem from restructuring of the gas and power sectors. A fourth scenario includes the *reform assumptions plus the lower economic growth* of the modified base case. Fifth, an *energy efficiency* case, is built on the higher-growth *energy sector reform* scenario, but goes further by testing the impact of reducing electricity consumption by five percent. Sixth, an identical efficiency case is run, but with the lower

---

20. See, for example, Wang To-Far, "Economic Restructuring for Sustainability in Taiwan," Conference Proceedings, "International Conference on Sustainable Energy and Environmental Strategies: Taiwan and the World," 28-29 September 2000, Taipei, Taiwan.

21. Levelized cost analysis of an energy system yields cost per kilowatt-hour for power generated. The approach incorporates capital, fuel, operating, and environmental costs, and produces a discounted net present value permitting comparison of system costs for technologies with differing lifetimes. See John H. Gibbons and William U. Chandler, *Energy: The Conservation Revolution* (New York: Plenum Press, 1980). Linear programming selects the least-cost combination of supply options.

22. Additional sensitivity tests have been run but not fully reported.

economic growth assumptions of the *modified base case*. Seventh, a *low emissions scenario* estimates the effect of relatively strict limits on the release of oxides of carbon dioxide. It is based on high economic growth assumptions, but a *low emissions with slow growth case* is also run.

It should be emphasized that the base cases in this study utilize the higher LNG fuel price assumptions made by Taipower. No sensitivity test is needed here for the higher prices, because the base case in effect serves that function, and the author makes no assertion that the base case conditions will not come to pass. Indeed, the purpose of the study is to test the effect of policy measures–such as gas sector reform–that could make a difference in Taiwan for reducing economic and environmental costs. While it might be desirable to test the effect of higher gas price assumptions on the efficiency or low carbon scenarios, the resulting increase in scenarios would probably serve to provide little additional guidance to policy makers but would greatly increase the complexity of this study.[23]

This analysis is designed to take account of current aspects of Taiwanese electric sector policy, including underlying goals of maintaining economic growth and minimizing the cost of electric power, ensuring the security and reliability of electric power supply, meeting environmental challenges, and liberalizing the electric power and gas supply sectors. This work examines supply-side and demand-side options for meeting future Taiwan electric power needs, options that include conventional coal, liquified natural gas, petroleum, and nuclear fuels, selected renewable energy and distributed power generation options, and end-use energy efficiency policies and measures. Nearer term supply- and demand-side technologies have been considered in greater detail, while longer-term technologies–defined as technologies not yet cost-competitive but offering important prospective advantages–have been characterized for planning purposes.

Methodology

The modeling methodology compares alternative sources of power generation in three steps. First, the user specifies projected power demand by region and time.[24] Next, the model converts the capital, fuel, operations, and associated environmental costs of selected power supply technologies to levelized cost per kilowatt hour. Finally, it estimates the least-cost combination of power supply options that meet the given demand. The user simulates alternative policies by defining "constraints" that change economic costs, pollution limits, or physical characteristics such as transmission capacity. *The reader is invited to pay special attention to a description of these constraints in pages 20-30 of*

---

23. Taipower is sensitive to the high LNG costs in part because they are constrained by official policy *not* to import gas directly, and by the imposition of "take-or-pay contracts" that limit their flexibility. There is also a scale issue in Taiwan for increasing the supply of gas, which is to say that port facilities and suitable harbors are limited and increasing imports beyond the thresholds of specific facilities could possibly drive up costs dramatically. Some analysts also worry that the global demand for LNG will outstrip supply and thus drive up prices, particularly if global climate policy drives up the demand for gas.

24. Power demand is modeled as kilowatt hours, not peak kilowatts. An adequate peak ratio is maintained in the model output by requiring an average load factor comparable to today. Average load factor is the ratio of kilowatt hours of demand to the maximum kilowatt output possible for installed capacity. In recent years, that value has averaged about 55 percent, which is not atypical for relatively well-developed economies.

this report. The results indicate increased or reduced economic cost compared to the baseline, along with changes in power plant capacity, power generation, and emissions of waste gases into the atmosphere.

The linear programming (LP) model applied in this study–the Economic and Environmental Power Planning model, developed by Jeffrey Logan–allows analysts to capture detailed characteristics of the technologies used in the power sector, an important consideration over the relatively short time scale considered (see Appendix 2.) A sub-routine in the LP model first calculates levelized costs for each type of power generation option based on capital, fuel, operation and maintenance, and environmental costs. The model then estimates the optimal combination of new plants needed to meet given levels of power demand, which is exogenously assumed and is based on Taipower studies.

One of the limitations of optimization models like the one applied here is its tendency to overestimate the impact of the least-cost alternative. For example, even if coal-fired power was only marginally cheaper than LNG-fired power, the model would select all coal-fired power unless it was constrained to do otherwise. Macroeconomic general equilibrium modeling might have been a preferred approach if Taiwan's power sector were open and competitive, but it is largely state-owned with investment choices determined and prices set by the government. Furthermore, these top-down models typically lack the technology options needed for a sector-specific study of the economy.

One important constraint on technology choice imposed in Taiwan has been both an explicit and implicit requirement for diversification of power supply to enhance security of supply. This practice stems from the need to import almost all fuels used in Taiwan, and is followed even when a supply choice is more expensive in direct costs. The linear programming model can account for such preferences by using constraints imposed by the modeler.

Baseline Projections by Taipower

Taipower annually performs a power generation and peak-load forecast for the next fifteen-year period. The load forecasting model, which was built and is maintained using in-house Taipower expertise, is a parametric economic model. Results are driven by Gross Domestic Product (GDP) projections, which Taipower adopts from various Taiwan sources, including the Council for Economic Planning and Development. Economic growth assumptions are critical for power demand projections because Taipower economists assume that GDP elasticity of demand for electricity will continue at close to 1.0 in the short-term, and slowly decline to 0.8 by 2020.[25]

25. The GDP elasticity of demand for electricity is the percentage change in electric power demand for each one percent change in GDP.

The March 2001 Taipower forecast assumed that economic growth would continue at a rate of more than 5 percent for the next five years, but would slow over time (see Table 4).[26] A precipitous drop occurred in the GDP growth rate in 2001, with first and second quarter GDP growth in Taiwan slipping to annual rates of 0.91 and -2.35, respectively. Because this study is based on long-term trends, the author chose to consider two alternative sets of cases based on robust and slower GDP growth rates. Near-term power demand will almost certainly be lower than recently expected, thus reducing the near-term need for capacity additions. Taipower analysts updated their 2001 forecast in September with much lower GDP estimates. For example, the Taipower September study puts year 2015 peak power demand some 9,000 megawatts below the March forecast (see Appendix 3 for details).

Table 4: Taiwan Economic Growth, 2000-2020 (percent per year)

Year	Taipower Forecast	
	March 2001	Sept. 2001
2001-2005	5.2	3.9
2006-2010	4.9	3.7
2011-2015	4.7	3.4
2016-2020	4.4	3.2

Source: Taipower Company, 2001

Taipower's forecasters pay special attention to industrial demand, which accounts for over half of the utility's sales.[27] Industrial power use in Taipower's model is driven mainly by GDP growth, modified by sub-sector trends. Industrial sector power demand is modeled in 15 sub-sectors, including energy-intensive industries such as chemicals and iron and steel, but also lighter industries such as "high technology." One equation describes demand in each sub-sector as a function of GDP growth, per capita income growth, population growth, electric power price, and price response. Coefficients, derived using regression analysis, are then used along with assumptions about GDP growth to project future sub-sector power demand. This approach provides an assessment of structural change in the economy. This work is reviewed by scholars of the relevant industries, and the derived trends are sometimes modified on the basis of their knowledge of trends in the sectors. For example, if a sub-sector is being encouraged or discouraged by government intervention, a corresponding coefficient can be adjusted accordingly.

Large-scale commercial sector customers such as hospitals are included in the industrial sector. Short-term projections also include consideration of average temperature, which helps to account for air conditioning loads.

26. See, "Data Confirms Bleak Taiwan Outlook," Reuters, 25 July 2001, published in *South China Morning Post*, also 25 July 2001.

27. Taipower provides about 85 percent of Taiwan's electricity.

Buildings Sector Demand Forecasting

The "lighting" sector, as defined by Taipower, includes smaller-scale commercial customers and all residential customers. Major power uses in this sector in Taiwan include air conditioning, refrigeration, appliances, as well as lighting. Future demand for electricity for air conditioning and similar "lighting" loads are modeled using econometric formulations based on per capita GDP, numbers of air conditioners times projected cooling degree days, electricity tariffs, and projected electricity price changes. Though the "lighting" sector does incorporate a function for price elasticity of demand, the continuous decline in the real price of electricity over the past two decades in Taiwan has undoubtedly softened consumer willingness to conserve.[28] This may change, however, as Taipower currently assumes a 2 percent real increase in the price of electricity. Moreover, this adjustment appears to be too modest both to rationalize electric power prices in Taiwan and to cover projected fuel price increases.

The Taipower load forecast considers conservation primarily for load management and mainly addresses peak demand. An estimate is made of the effectiveness of these programs and after the model is run, that effect is subtracted from peak demand.[29]

Technical energy efficiency has traditionally not been taken into account in buildings sector load forecasting for Taiwan. But Taiwan has recently moved to enact energy-efficiency standards. These standards, however, appear not to apply to the bulk of market purchases. The standards rank below the best products identified in the U.S. government "Energy Star" program (see Table 5).[30]

Table 5: Efficiency Standards in Taiwan[1]

Type	Efficiency Unit	Standard	*Energy Star*[2] Best Model
Window AC (<3 kW)	EER (BTU/Watt)	8.7	11.5
Central AC	EER (BTU/Watt)	11.5	16.0
Refrigerator (400 liters)	kWh/year	890	394
Fluorescent lighting	Lumens/Watt	>44	>70
Office Buildings[3]	kWh/square meter/year	<130	

Notes:
1. Standards set by Energy Commission, Ministry of Economic Affairs
2. *Energy Star* is a rating and labeling program of the U.S. government; the levels

28. Price elasticity of demand is defined as the percentage change in electric power consumption as a function of a one percent change in the price of electricity.

29. Additional information for the residential sector is available at http://btscoredatabook.eren.doe.gov/.

30. Recommendations are made by the U.S. Environmental Protection Agency and the U.S. Department of Energy in the "Energy Star" program. The goal of this program is to encourage consumers to move beyond the level of efficiency mandated by a number of efficiency standards to achieve a higher rate of energy savings, but at a level cost-effective for consumers as well as beneficial for the environment.

Residential housing in Taiwan is dominated by multifamily buildings made of reinforced concrete. Efficiency standards exist for both building construction thermal performance and air conditioning, however, these are new, having been published only five years ago. Air conditioning loads are significant in the humid summer and continue to grow rapidly. Shipments of air conditioning units for sale in Taiwan have averaged 1.8 million per year over the past five years, 10 times more than in 1980.[31] An ironic joke among Taiwan energy analysts suggests that shop keepers leave open their doors in the hottest part of summer to entice customers inside with the flow of cool air onto the hot, muggy streets. Significantly, power demand modeling in Taiwan does not currently incorporate any variable for the energy-efficiency of air conditioners.[32]

Projecting Power Generation Costs

The modeling effort conducted in this study incorporates several conventional and new power generation technologies, including coal-fired power plants with scrubbers, oil-fired combined-cycle units, gas-fired combined-cycle units, nuclear power plants, hydro power plants, integrated coal (or refinery waste) gasification combined-cycle (IGCC) plants, biomass gasification plants, wind, and fuel cells. Taipower applies levelized cost analysis–as does this report–to assess the economic costs of power system options. Supply-side options are evaluated on the basis of twenty-five year economic lifetimes, as a matter of government policy. This time period is used regardless of the physical life, and should be distinguished from the lifetimes assumed for purposes of depreciation and taxes.

The levelized cost analysis performed for this study incorporates Taipower assumptions, modified where the author believes policy changes would make a difference in capital, fuel, or operating costs (see Table 6).

31. "Shipment of Appliances in Taiwan Area," *Taiwan Energy Statistics, op cit.*

32. Personal communication, Taipower Corporation, March 2001.

Assumptions for capital costs per unit of generating capacity are obviously important, as are assumptions for capacity factor–the percent of time that a plant is expected to generate power (Tables 6-8 present major assumptions by technology, with a summary of levelized costs included in Table 8). Such variables are considered in the context of the scenarios, because certain assumptions have been changed to reflect expected changes in the use of technology as a result of policy changes. To give a significant example, the capacity factor for LNG-fired plants varies from a low rate that reflects the current practice of using LNG facilities for meeting peak and intermediate loads to a higher one–particularly in the energy sector reform case–to simulate base load operation.[33] This particular assumption has an important impact by reducing the cost of power generation for this relatively clean fuel. However, the capacity factor for this technology, which is the most flexible in terms of load-following, was limited in several cases by the need to match capacity to peak load requirements. It should be noted that in Taipower's own models, capacity factor is an output to be optimized, not an assumption. The lower capacity factor usually resulting for LNG-fired plants is a function of the lower discount rate and higher LNG prices assumed by Taipower than is assumed by the author for all but the base case in this study.

Table 6: Power Supply Technology Assumptions, 2000-2020

Item	Capacity Factor (percent)	Conversion Efficiency (percent)	Time to Build (years)	Lifetime (years)
Coal, Wet FGD	70	36	4	30
Combined Cycle (LNG)[1]	42/75	55	3	25
Cogeneration (Coal)	50	45	3	25
Nuclear	80	33	7	30
Wind	36	85	2	20
Biomass Gas Combined Cycle	65	41	2	25
Fuel Cell (LNG)	75	60	1	20

1. The first value is the recent rate reported by Taipower; the higher value is standard practice in many plants around the world. The actual rate applied in a specific scenario in this study depends on the need to provide adequate peaking capacity. When higher peaking capacity is required, a lower capacity factor is assumed. In some cases, low-cost simple cycle turbines are assumed in order to meet peak loads.

Fuel costs are a matter of record for the base year, of course, but then the analyst must choose a rate of change in those prices, and because any percentage rate of increase is exponential, the result after 20 years can be decisive. Also, there is the matter of distorted prices, particularly for LNG, as explained below. Other assumptions have smaller but important impacts, including the length of time required to build a power plant, which affects the interest charge that must be paid during the construction period. Construction time assumptions can critically affect capital-intensive technologies such as nuclear and hydroelectric power. Finally, the discount rate is important because higher discount rates have greater effect on technologies with higher capital costs. In this study, we have chosen not to

33. Modern combined-cycle plants are now typically operated in base load configuration. See, ICF Consulting, "Carbon Emissions World Outlook Winter 2000/2001," available at http://www.co2e.com/images/ICF%20Market%20Outlook%20Exec%20Sum.pdf, and http://www.eia.doe.gov/cneaf/electricity/chg_str_fuel/html/chapter5.html.

use the *financial* interest rate, which would be the rate paid to a lender, but rather the *economic* discount rate, which refers to the opportunity cost of money. Weighing an investment against other productive uses in the economy is the most appropriate economic measure. This study therefore applied a 10 percent discount rate.

The discount rate assumed by Taipower is equal to the interest rate Taipower pays, which is in the range of 6-6.5 percent above inflation. That level is relatively low because the utility is state-owned and effectively enjoys a financial sovereign guarantee. Formerly, Taipower was required to generate a real return on investment (ROI) of 10 percent.[34] The Taiwanese government officially permits ROI for the utility to range from 9.5 to 12 percent. Recently, however, higher capital and fuel costs have reduced returns to an average of 6 percent and to only 4.4 percent in 2000. Poor recent performance is at least partly due to the cost of rebuilding and recovery after a devastating earthquake in September 1999.

Fuel Cost Assumptions

The price of liquified natural gas (LNG) in Taiwan is comparatively high and is expected to remain that way. LNG prices charged at the source are similar for Taiwan and Japan, but Taiwan delivered costs are much higher than in Japan due to Taiwan's severely constrained port facilities and the effective monopoly on the LNG market held by China Petroleum Corporation. Taipower is not, in practice, permitted to import LNG–that is, the company cannot go directly to the market and buy the fuel, or even enter into a joint venture for LNG supply. Efforts to introduce competition in LNG supply have included a Taipower recent tender for a 20 year contract, but the purchase was canceled when only two of the requisite minimum of three suppliers bid for the contract. LNG is further disadvantaged by the imposition of a 7.5 percent excise tax on LNG used by Taipower, a fee which is not assessed against coal and oil. Taipower estimates the future price of gas by taking a ratio of the

34. As part of a financial arrangement with the World Bank.

high price–relative to world market or Japanese price levels–they are charged by the China Petroleum Corporation as a baseline and extrapolating that level at the same rate of increase they assume for the world oil price. The result is a projected real price increase for LNG of over 2 percent per year for the next two decades. Fuel oil is projected by Taipower to increase at a similar rate (see Table 7).[35] This study, however, applies a petroleum fuel price increase of just over 1 percent real, or above inflation, per year, as projected by the U.S. Energy Information Administration.

Table 7: Taiwan Fuel Price Assumptions for Electric Power Generation, 2000 and 2020

	Unit[1]	Actual 2000	Projected 2020
Bituminous Coal	US$/ton	31	38
Fuel Oil (#6)	US$/GJ	4.78	6.90
Liquefied Natural Gas	US$/GJ	5.87; 4.00[2]	7.20; 5.78[2]
Nuclear Fuel	US$/kWh	0.004	0.006

1. All prices in year 2000 dollars. 2. The world price–essential the price in Japan–was used for the year 2000. The distorted price paid in 2000 in Taiwan was US$5.87.

Sources: Taipower Corporation, Battelle Memorial Institute, 2001; price of coal from Wang Hui-Sheng, private communication, March 2001 and Graphic 4-66, Taipower Corporation March 2001.

Small amounts of coal are produced in Taiwan, but the quality is low and the price high. Most coal is imported and comes mainly from sources in Indonesia–through spot market purchases, Australia, and South Africa. Taipower projects coal prices to rise at an annual real rate of roughly 1 percent rate per year for the next two decades, markedly slower than the assumed increase in petroleum prices.

Nuclear fuel cost is a small part of the overall cost of generating power from atomic energy, and uranium prices generally do not significantly affect the projected overall cost of nuclear power. Taipower's assumed rate of nuclear fuel price increase of 2 percent per year for the next two decades does not change that condition. As detailed above, a decommissioning charge is added to the cost of nuclear electric power.

Consideration of Alternative Power Sources

The existence of independent power producers complicates power planning and forecasting, particularly because law requires Taipower to buy power at avoided cost, including transmission and distribution costs. Some observers suggest that many qualifying facilities, or cogenerators, are not efficient producers but qualify for high rates of payment from Taipower because they meet the low efficiency required.

35. Note that the 2 percent real electricity price increase assumed by Taipower is higher than the real fuel price increases–with the exception of LNG–but that the difference by itself is much too low to eliminate by 2020 the electricity price subsidies that now exist.

It should be noted that distributed power generation–small-scale power production in buildings, homes, and factories–has the potential with the appropriate development of new technology and reasonable LNG prices to alter dramatically the nature of the utility sector. However, capital costs for technologies such as fuel cells will need to decrease to be attractive to industry and building operators.

Table 8: Levelized Power Supply Costs in Taiwan, 2010, by Technology[1]

Technology	Capital Cost	Capacity Factor	Fuel Cost	Total Cost
	$/kW	%	$/GJ	$/kWh
Coal, Wet FGD	750	70	1.30	0.04
Combined Cycle (LNG)[2]	463	75	4.42	0.05
Cogeneration (Coal)	750	50	1.30	0.04
Hydroelectric	2,741	33	-	0.09
Nuclear[3]	2,100	80	0.45	0.06
Wind	950	36	-	0.06
Biomass Gas Combined Cycle	1,900	65	1.00	0.06
Fuel Cell (LNG)	2,500	75	4.42	0.08

1. Levelized costs for all cases except the two base cases, which use higher LNG prices and lower combined cycle capacity factors.
2. Capacity factor is 42 percent in the base and modified base cases because Taipower uses LNG plants for intermediate and peaking loads. All other scenarios use 75 percent, which implies gas sector reform and a shift in power sector incentives.
3. Includes decommissioning costs.

Source: Data from Taipower Corporation and Battelle Memorial Institute; data and calculations by Battelle Memorial Institute, 2001.

Taipower experts generally do not consider renewable energy sources to offer large amounts of energy supply, though they say they remain open to that possibility. Their view extends to Taiwan's hydroelectric resources, which are high in capital cost. The original, theoretical hydropower resource totaled about 10,000 megawatts, but the technically available total amounted to only half that. With installed hydroelectric capacity now at 1,820 megawatts, the remaining resource would have seemed substantial, but the capital cost for one hydro facility under construction exceeds US$3,100 per kilowatt, several times that of a modern coal-fired plant. Even though hydropower has zero fuel cost, high capital requirements make it uncompetitive. The amount of new hydroelectric power facilities planned or under construction totals around 200 MW. Probably less than 150 MW of hydropower capacity is available for additional exploitation, though one 600 megawatt pumped storage plant is being considered in the northern portion of the island.[36]

36. Pumped storage plants are really not a "source" of energy but a storage technique used to meet peak power demand. Water is pumped behind a dam using off-peak power and then allowed to flow over turbines to

Wind power is generated in two projects, the *Ponghu* and *Mailiao* wind power stations located on islands off Taiwan's west coast, with a total of 5.04 megawatts. These plants were intended to operate at a 30-36 percent capacity factor–the percentage of time in which power is actually being generated.[37] Some of the turbines were produced in Taiwan by a company under license by Mitsubishi, though the Mailiao station uses Danish Vestas machines. The author is not aware of any plans to expand wind power generation in Taiwan.

Utilization of geothermal power generation has been limited. A few plants were built but some have been closed due to high cost, which stems from a high sulfur content of the water and a declining steam pressure level in the wells.

Taipower system planners expect coal to remain its largest source of power generation. The utility currently operates only sub-critical coal-fired plants, but plans to add a 750 MW super-critical coal-fired plant, and may in the future choose 1000 MW super-critical coal-fired plants with an efficiency of 38 percent.[38] Capital costs for these plants compare favorably to nuclear power but are more costly than natural gas-fired plants, though of course coal costs much less than gas. All new conventional coal-fired power plants will be required by law to incorporate flue-gas desulfurization and particulate removal. A small (300 MW) demonstration project is planned to test integrated gasification combined cycle (IGCC) technology, but the capital cost data are not available. IGCC is considered by Taipower to be attractive than pressurized fluidized bed combustion (PFBC) because IGCC obtains higher overall efficiency.

The cost of nuclear power generation is dominated by the cost of capital. This study assumes that future nuclear power capital costs would be similar to recent estimates for completion of Nuclear Power Plant Number 4. A new nuclear power plant, ordered today, would most likely cost over US$2,000 per kilowatt, although Russian-made systems may be less expensive. Operating costs assumed in this study–and by Taipower in its modeling efforts–include contributions to a sinking fund, or "waste fuel fund," for nuclear waste disposal and power plant decommissioning costs. These costs in current dollars at the end of the operating life for nuclear plants total over US$300 million per unit. However, economic discounting renders these costs less prominent in present dollars than one might intuitively expect–adding only US$0.005 per kilowatt-hour. Taipower has collected US$3.7 billion for waste disposal and decommissioning since 1987.

---

generate power–with some efficiency loss due to pumping–during periods of peak demand.

37. One recent survey suggested that the stations' capacity factors may in practice actually be lower.

38. Sub-critical in this context refers to coal-fired plants that operate without superheated steam, and are thus less efficient than the most modern plants. Taipower power engineers express some concern about this technology due to its novelty.

Scenario Analysis

The scenario analysis is constructed to highlight the implications of a few fundamental policy and technology choices. Future demand is driven by assumptions for GDP growth, and half the scenarios presented below are based on the high GDP growth assumed by Taipower in its March 2001 forecast, and half are based on the much lower GDP growth projected by Taipower in a September 2001 forecast. A baseline case is intended to demonstrate the least-cost configuration of power generation assuming the *status quo*, which is to say continued dominance of the power sector by the state-owned and regulated utility Taipower Corporation, and with little or no restructuring in the fuel supply sector. The modified baseline case tests both the effect of lower GDP growth now projected by Taipower and the effect of early retirement of older nuclear power reactors. Two energy sector reform cases–one with high and one with low GDP growth–test the impact of opening up both the power and fuel markets to private competition. Two energy efficiency cases–again, high and low GDP variants–assess the plausibility of cutting power generating costs through price reform, economic restructuring, and demand-side efficiency measures such as improving air conditioning equipment. Two low emissions scenarios, again, differing only in the rate of GDP growth assumed, assess the effect on power costs and technology choice of a high tax on carbon dioxide. Sulfur emissions are assumed to be strictly controlled in all scenarios.

While future power demand is a function of GDP growth, it is adjusted by a decline in the GDP elasticity of electric power demand. GDP elasticity is defined as the percent increase in power demand for every one percent increase in GDP, and in most developed countries is at or below 1.0. In Taiwan, that elasticity is projected by Taipower to decline from its recent historical level above 1.0 to as low as 0.8 by 2015.[39] It should be noted that the slightly reduced demand levels in the efficiency forecasts are hypothetical technical energy-efficiency improvements that plausibly could be implemented through standards, incentives, and information programs, and do not involve projections of changes in economic behavior based on prices or incentives.

The scenarios include all power produced and consumed on the island, not just the share produced by Taipower. Island-wide demand is scaled up from the Taipower projection assuming, as Taipower does, that its share of electric power will decline to around 70 and 60 percent by 2010 and 2020, respectively.[40] This change is expected even without privatization of Taipower, as power generated by IPPs is expected to continue to grow.

---

39. The actual values reported by Taipower for their projections vary significantly by year, but when smoothed by averaging over five-year periods indicate a general downward trend. The five-year averages for 2000-2005 are 1.006 and 0.9654 for the March and September scenarios, respectively, and for 2010-2015 are 0.818 and 0.850. The latter pair is interesting for its combination of higher elasticity with the lower GDP growth assumption.

40. That is, independent power producers and cogenerators are constrained not to take market share from Taipower.

Other noteworthy assumptions affecting results in all scenarios include the following:

- The real–above inflation–discount rate for all periods is 10 percent. Although the interest rate is lower, the opportunity cost of capital is best reflected by the discount rate, not the interest rate.
- The exchange rate for new Taiwan dollars to U.S. dollars is 31.23. Though the value of NT$ has declined, this rate was used for the original estimation of capital costs and reflects real costs.[41]
- Significant amounts of biomass are assumed to be unavailable for power generation. The potential for energy plantations in Taiwan has not been seriously explored for this study, meaning that this assumption could be misleading.
- Fuel imports are unconstrained, but no fuel type is allowed in the model to generate more than half of total power, except in a sensitivity test case not reported here. This approach is similar to but less restrictive than stated policy in Taiwan, and is not very different from current reality, in which coal accounts for more than two-fifths of all power generation in Taiwan.

Scenario cost results include the incremental costs of power supply compared to power system generating costs in 2001.These estimates include the cost of adding and operating new generating capacity as well changes in the operation of generating capacity already in existence in 2001. It should be noted, however, that economic costs do not fully account for changes in costs to Taipower or independent power providers, who could gain or lose financially depending on circumstances. For example, if Taipower shuts down nuclear capacity early, it may lose the benefit of sunk capital costs and incur higher costs to acquire power from independently owned coal-fired plants. From the economic (as opposed to financial) point of view, the total cost of capital, fuel, and operation of nuclear plants would be higher on a life-cycle basis than that of the coal-fired plants. But from a financial point of view, and as far as the utility's balance sheet is concerned, there would be a loss. This observation by no means is meant to imply that policy makers should make decisions on the basis of their financial impact. But it does imply that policy makers must take such impacts into account if their policies are to produce the desired behavioral response.

Results for the scenarios are reported in the scenario descriptions and accompanying tables below (see Tables 9-12).

Baseline Scenario: The baseline scenario establishes a context against which alternative futures can be evaluated. It describes the existing power generation and transmission system, recent electric power consumption and utilization characteristics, and anticipated changes in supply and demand assuming the *status quo ante*, which is to say the baseline projected by Taipower in its March 2001 demand and supply forecasts. This baseline case addresses the reliability, security, and affordability of Taiwan's electric power supply, but assumes continuation of policies and conditions in place in the first quarter of 2001. In this future, the Fourth Nuclear Power Plant would be completed, and no other constraints would be placed on nuclear power. LNG import costs would remain high due to the existing monopoly situation, and coal would be constrained to supply no more than half of all power, even if it is the cheapest source.

---

41. See, "Fuel Characteristics," Taipower Corporation, March 2001; personal communication, Wang Hui-Sheng, 23 May 2001, working session at Battelle, Pacific Northwest National Laboratory, 22-23 May 2001.

Table 9: Terawatt-hours by Scenario (TWh)	**2000**	**2005**	**2010**	**2015**	**2020**
Base Case					
Coal	99.4	111.3	143.3	179.7	227.9
LNG and Oil	39.8	64.8	93.8	93.8	93.8
Nuclear	38.3	55.0	55.0	94.7	120.8
Hydro & Renewable	8.6	8.1	11.4	13.2	15.0
Total	186.2	239.2	303.4	381.4	457.4
Modified Base Case					
Coal	99.4	108.5	132.1	156.4	189.1
LNG and Oil	39.8	53.3	91.4	130.0	150.2
Nuclear	38.3	55.0	34.2	18.9	18.9
Hydro & Renewable	8.6	7.9	11.4	13.2	15.0
Total	186.2	224.7	269.2	318.5	373.2
Energy Sector Reform Case					
Coal	99.4	124.1	155.5	187.3	234.6
LNG and Oil	39.8	50.5	101.8	162.1	189.7
Nuclear	38.3	55.0	34.2	18.9	18.9
Hydro & Renewable	8.6	9.0	11.9	13.1	14.2
Total	186.2	238.6	303.4	381.4	457.4
Energy Sector Reform Case, Low Growth					
Coal	99.4	115.1	143.5	173.3	212.6
LNG and Oil	39.8	64.3	80.5	113.5	127.1
Nuclear	38.3	36.0	34.2	18.9	18.9
Hydro & Renewable	8.6	9.3	11.0	12.8	14.6
Total	186.2	224.7	269.2	318.5	373.2
Energy Efficiency Case					
Coal	99.4	128.1	154.2	182.7	221.2
LNG and Oil	39.8	40.3	88.3	139.7	170.8
Nuclear	38.3	55.0	34.2	18.9	18.9
Hydro & Renewable	8.6	9.7	12.6	13.7	14.9
Total	186.2	233.0	289.3	355.0	425.7
Energy Efficiency Case, Low Growth					
Coal	99.4	116.9	143.8	169.7	186.0
LNG and Oil	39.8	62.5	67.1	79.6	79.6
Nuclear	38.3	36.0	34.2	18.9	18.9
Hydro & Renewable	8.6	9.3	11.0	12.8	12.8
Total	186.2	224.7	256.2	281.1	297.3
Low-Carbon Case					
Coal	99.4	105.6	111.8	108.2	108.2
LNG and Oil	39.8	77.5	120.5	196.4	258.2
Nuclear	38.3	36.0	34.2	18.9	18.9
Hydro & Renewable	8.6	13.8	22.7	31.6	40.4
Total	186.2	233.0	289.3	355.0	425.7
Low-Carbon Case, Low Growth					
Coal	99.4	105.6	111.8	130.0	137.3
LNG and Oil	39.8	69.2	87.4	100.6	100.6
Nuclear	38.3	36.0	34.2	18.9	18.9
Hydro & Renewable	8.6	13.8	22.7	31.6	40.4
Total	186.2	224.7	256.2	281.1	297.3

Power demand, which drives the scenario, is assumed to increase from 186 terawatt hours in 2000 to 457 terawatt hours in 2020. Total Taiwan power capacity is estimated to increase from roughly 39,000 megawatts in 2001 to 95,000 megawatts in 2020. The incremental discounted cost over this period of providing new power supplies is estimated at $137 billion. This level is the highest cost of any of the scenarios in this study for three main reasons. First, the base case incorporates Taipower's March 2001 power demand projection, which is much higher than in many subsequent scenarios. The subsequent scenarios incorporate the much lower September 2001 GDP projections made by Taipower. Second, the price of natural gas assumed by Taipower is much higher than the world price, and measures in subsequent scenarios including gas sector reform are assumed to reduce LNG price levels. Third, the base case modeling is constrained to allow no more than roughly half of all power to be composed of coal-fired generators, the ratio in 2000. As a result, the model is forced to choose expensive alternatives to satisfy the very high demand projection of the March 2001 forecast. At least half the difference between the cost of the base case and the gas reform scenario, the next most expensive case, is due to the simple difference in the price assumption for LNG. Some of the rest of the difference in cost is due to Taipower's assumption that LNG-fired capacity is used only for meeting intermediate and peak load, which means that the capacity factor of these plants is only 42 percent compared to an assumed 75 percent in subsequent scenarios. Higher capacity factor can mean a lower capital cost for kilowatt hour generated, and in turn a lower total cost per kilowatt hour.[42]

Base case carbon emissions from the power sector double–or, more precisely, to 2.08 times the year 2000 level, an increase from 28 million to 57 million tons per year.[43]

Modified Baseline Scenario: This scenario utilizes the dramatically reduced Taiwan GDP projection of September 2001. Taipower's September power forecast revised GDP growth downward from a 4.9 percent annual growth rate over the next two decades to 4.1 percent. Consequently, the power demand projection was reduced from 4.3 to 3.3 percent annually over the period.[44] The lower rate translates into expected power demand in 2020 of 373 terawatt hours, only 80 percent that of the base case. Capacity requirements grow from today's 38,800 megawatts to 87,000 megawatts. The base case incremental cost is US$ 170 billion or about 80 percent of the base case cost estimate, including the cost of replacing nuclear units retired early.[45]

---

42. This gas-fired plant capacity factor issue is a complicated and difficult one, however, because of the need to satisfy peak demand, and the fact that gas-fired plants are the most flexible in load following.

43. It is important to note that these costs are the costs of meeting new demand and shifting existing generation to a different configuration, and not the total cost of meeting demand.

44. These rates correspond to the assumed GDP rates modified by the changes in GDP elasticity of demand for power expected by Taipower over the coming two decades.

45. Again, these are the costs of meeting new demand and shifting existing generation to a different configuration, and not the total cost of meeting demand.

Table 10: Generating Capacity (GW)	2000	2005	2010	2015	2020
Base Case					
Coal	19	21	28	36	46
LNG and Oil	10	17	25	25	25
Nuclear	5	8	8	14	17
Hydro & Renewable	4	5	6	6	6
Total	39	51	66	80	95
Modified Base Case					
Coal	19	20	26	31	38
LNG and Oil	10	14	24	35	40
Nuclear	5	8	5	3	3
Hydro & Renewable	4	4	6	6	6
Total	39	47	60	74	87
Energy sector reform Case					
Coal	19	23	29	35	44
LNG and Oil	10	10	19	28	33
Nuclear	5	8	5	3	3
Hydro & Renewable	4	4	5	5	5
Total	39	46	57	71	85
Energy Sector Reform Case, Low Growth					
Coal	19	22	26	29	35
LNG and Oil	10	12	16	23	27
Nuclear	5	5	5	3	3
Hydro & Renewable	4	5	5	5	5
Total	39	44	51	60	69
Energy Efficiency Case					
Coal	19	23	27	33	39
LNG and Oil	10	11	19	26	27
Nuclear	5	8	5	3	3
Hydro & Renewable	4	4	5	5	5
Total	39	46	56	66	74
Energy Efficiency Case, Low Growth					
Coal	19	22	26	29	33
LNG and Oil	10	12	15	20	20
Nuclear	5	5	5	3	3
Hydro & Renewable	4	5	5	5	5
Total	39	44	50	56	61
Low-Carbon Case	19	20	20	19	19
Coal					
LNG and Oil	10	16	24	34	39
Nuclear	5	5	5	3	3
Hydro & Renewable	4	5	6	7	9
Total	39	45	54	63	69
Low-Carbon Case, Low Growth					
Coal	19	20	20	19	19
LNG and Oil	10	14	19	26	28
Nuclear	5	5	5	3	3
Hydro & Renewable	4	5	6	7	9
Total	39	43	49	54	59

Energy Sector Restructuring Scenario: This scenario builds on the baseline scenario demand projection and tests the impact of energy supply market liberalization, power supply competition, and early retirements of older nuclear power units. The last item is included because some observers assume early nuclear retirements are an implicit outcome of the sharp debate in 2000 and 2001 on the future of nuclear power in Taiwan. Existing nuclear capacity is assumed to be retired when reactors reach an age of 26-28 years.[46]

A policy model for a competitive power supply system might be the example of Argentina, though comparison and contrast should also be made with the unsuccessful transition to market-based competition in California. In the case of California, power costs escalated out of control because the state law implementing reform prohibited long-term power purchases and failed to discourage anti-competitive behavior and capped retail but not wholesale pricing.[47]

But the greatest impact on results in this scenario stems from LNG supply restructuring. The cost of LNG is assumed to drop to world levels as a result of liberalization in the gas supply sector. In 2020, for example, LNG would cost only US$4.90 per gigajoule in this scenario compared to US$7.20 in the baseline. Morever, even the high baseline scenario LNG cost is lower than that assumed in the Taipower scenarios, which assumes an increase in petroleum prices of 2 percent or more over the period. All scenarios included in this current study adopt the U.S. Department of Energy assumption of a 1 percent petroleum price increase as the most likely increase. This assumption appears also to be more consistent with Taipower's assumptions for coal price increases of just over 1 percent per year.

A complicating factor in this scenario and others that use relatively large amounts of LNG is the capacity factor assumed for gas-fired power plants. Modern combined-cycle plants around the world operate at 75 percent–a base load level–compared to the 42 percent assumed by Taipower in its forecasts and adopted here in the base scenarios. The lower rate, in fact, reflects current practice at both Taipower-owned and independent LNG-fired power plants in Taiwan, which are used to meet peak and intermediate loads. This practice reflects the realities of economic dispatch when capital already exists and the marginal cost of plant selection is simply a matter of fuel cost. Dispatch is a matter of selecting plants with the lowest variable costs. But the perspective can differ when the problem is selecting new capacity, when full life-cycle costs must be considered. An assumption of higher capacity utilization results in a lower cost estimate and, if appropriate, leads to increased selection and use of relatively clean LNG. However, sufficient peaking capacity must be provided,

---

46. The model, however, operates in five-year increments, which means that an early retirement of 2-3 years can be obscured by low time-scale resolution.

47. See, Energy and Mining Sector Board, "The California Experience With Power Sector Reform: Lessons for Developing Countries," World Bank, Washington, D.C., March 2001.

and gas-fired power is the most flexible and economic for meeting peak loads, implying that a lower capacity factor can be acceptable. The energy sector restructuring scenario pushes the capacity factors for gas-fired systems higher while meeting peak demand.[48] Doing so implies–but does not require–the freeing of cogeneration and LNG-fired plant managers to behave as if they were market actors seeking to maximize their profits. This behavioral change could come about as a result of privatization of Taipower or increased competition from independent power producers. The year 2010 cost of generating power with LNG ranges from US$0.042-0.060 per kilowatt hour, depending on the capacity factor assumed. Even the higher cost is a reduction from US$0.074 in the baseline, but chiefly as a result of introducing world price levels for LNG in Taiwan, which in turns implies the introduction of competition in the gas supply sector.

Nuclear power capacity in this restructuring case assumes that, as in the baseline case, Nuclear Plant Number Four is completed in the 2005-2010 period. That means that, for the base case 7,844 nuclear megawatts are in service through 2015, when 1350 megawatts of nuclear capacity reach the end of their expected service life. The energy sector restructuring scenario also assumes, however, that in 2010 two 636 and two 985 megawatt plants of older, boiling water nuclear power plants are retired, a few years ahead of their planned service lives. Relative to the baseline case, this policy change produces a relatively slight shift to more coal- and LNG-fired capacity, but the slack primarily is taken up by higher utilization rates–higher capacity factors–in LNG-fired plants.

The energy sector reform scenario cuts incremental power sector supply costs over the 2000-2020 period to $121 billion, or 88 percent of the base case. Obtaining this result through energy sector restructuring would require major policy initiatives to inject private ownership and competition in both the gas and power supply sectors. Priorities would include eliminating the near-monopoly position of the China Petroleum Company, and providing sufficient infrastructure for gas-handling port facilities and for storage.

Carbon emissions in this scenario actually increase relative to the base case, for two reasons. First, nuclear power plants are retired early to meet environmental goals and, in contrast to the base case, no new nuclear starts are permitted. There is a difference of 14 GW in nuclear capacity between the two scenarios. Second, the lower cost of LNG drives the model to select more carbon-based fuel, driving up carbon-fueled capacity by 15 GW compared to the base case. Together, these changes increase carbon emissions from 28 million tons from the electric power sector in the year 2000 to 67 million tons in 2020, or 10 million tons more than in the base case in 2020.

Energy Sector Restructuring/Revised GDP Scenario: This scenario replicates in all ways the energy sector restructuring scenario above, except that demand for power corresponds to that of the

48. The model used in this study does not consider peak loads in any detail and so an approximation is used instead. The figure of merit for adequate reserve capacity is the average load factor, which is the percentage of time that system-wide capacity is in use. That figure in recent years has averaged about 55 percent, and so all scenarios are required in the modeling to acquire capacity totals sufficient to maintain that level. That level is achieved in the modeling in one of two ways. First, the capacity factors of LNG-fired combined cycle plants are adjusted within a range of 33-75 percent. Second, if the first adjustment fails to provide adequate capacity, peaking combustion turbines are added to the mix and their capital cost added to the total for that scenario.

modified base case. The reforms reduce costs compared to about 90 percent of the modified base, a difference of over $10 billion. Carbon emissions are 57 million tons in 2020, 10 million tons below the energy sector reform/high economic growth scenario, and the same as the March 2001 Taipower high-economic growth base case scenario.

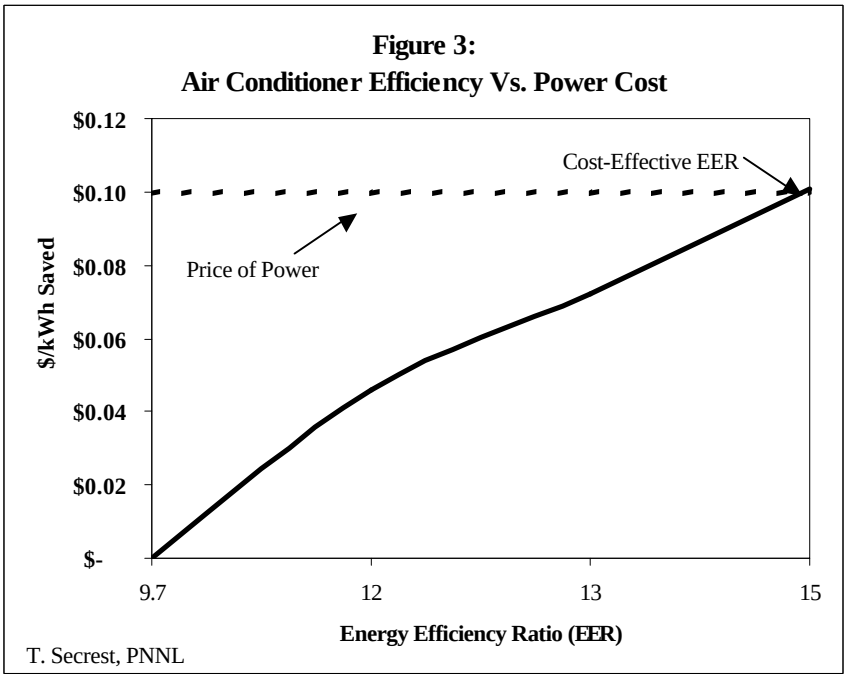
Energy-Efficiency Scenario: This scenario includes Taipower's planned load management programs and incorporates energy-efficiency measures that may be implemented with Taipower's cooperation, but with critical outside leadership. Examples of policies and measures that might be cost-effective for Taiwan's consumers include air conditioning and lighting energy-efficiency standards, building energy-efficiency construction codes, and tax incentives for industrial energy-efficiency investment. Such measures require action beyond the authority of Taipower and affect the total costs of electric power supply and use that must be measured on a life-cycle and total systems basis, in contrast to consideration of only power supply costs and tariffs.

Table 11: Total Cost, 2000-2020	**Billion Dollars New Costs**
Base Case	$137
Modified Base Case	$107
Energy Sector Reform Case	$121
Energy Sector Reform Case, Low Growth	$96
Energy Efficiency Case	$111
Energy Efficiency Case, Low Growth	$84
Low-Carbon Case	$136
Low-Carbon Case, Low Growth	$88

The technical plausibility of this scenario can be noted by comparing the level of efficiency for central air conditioners as mandated by Taiwan's energy efficiency standards–which apply only to government facilities–and the level that is cost-effective. The marginal delivered cost of electric power in Taiwan can be taken to be the wholesale cost of LNG, or about US$0.066 per kilowatt hour. This cost is the unsubsidized price level against which energy savings and alternative energy sources should be compared. Adding transmission and distribution costs brings the marginal cost to about US$0.10 per kilowatt hour. At that level, an energy-efficiency standard for central air conditioners for building ratepayers would be an energy-efficiency ratio (EER) of 16. The standard in Taiwan, however, is an EER of 9.3-17.5, and does not even apply to commercial establishments. The level of efficiency of most air conditioners in Taiwan–the fastest growing source of peak demand–is probably much lower than is cost-effective (see Figure 3.) Taipower, of course, has no control over the imposition of standards, and does not receive any special incentives to promote the adoption of higher-efficiency equipment.

Power demand in Taiwan is projected by Taipower (and in the previous cases, above) to grow about 90 percent as fast as the Taiwanese economy over the next decade. This rate will mark a shift from recent history during which power demand grew faster than GDP. This rate of growth is slower than in many developing countries, in which power demand usually outstrips GDP growth.[49] Typical

49. Income elasticity of energy (power) demand is the ratio of growth in energy (electricity) consumption to that of GDP growth. For more information, see Sinton, J. and M. Levine. 1998 "Energy Efficiency in China: Accomplishments and Challenges." *Energy Policy*, 26 (11): 813-829.



industrialized countries have values close to 1 for elasticity of energy and electricity demand. The ratios are higher for industrializing countries, averaging about 1.2 for elasticity of energy demand and 1.3 or higher for elasticity of electricity demand. A very small price elasticity–as little as 0.15–and a 2 percent annual real price increase would be sufficient to account for a downward shift in demand of 5 percent. Similarly, restructuring of the Taiwanese economy away from the materials intensive structure of the past five decades to one based on higher value-added manufacturing and products would also generate such an outcome. That is, shifting just 10 percent of the old economy to this "new" economy could have such a result.

The cost savings of this scenario are potentially large. These savings, however, would be offset by incentive and regulatory program costs, though probably not in full. It is beyond the scope of this study to provide a detailed estimate of the total benefits and costs of this scenario, although the result is sufficiently promising to warrant additional investigation by Taiwanese energy experts. Potential savings would justify an investment in efficiency incentives up to US$11 billion for Taiwanese consumers over the 20-year period. That is the amount in power generating costs between the efficiency scenario and the energy sector restructuring case. If demand could be reduced by the amounts suggested–2.5, 5.0, and 7.5 percent in 2010, 2015, and 2020, respectively–then the cost of energy saved could cost US$0.10 per kWh, the avoided cost of delivered power in Taiwan.[50]

Energy Efficiency Case/Revised GDP Scenario: This scenario, based on GDP growth rates used in the modified base case, results in year 2020 capacity requirements some 14 percent below the Taipower March projection. This scenario would meet expected power supply requirements of a still relatively healthy economy. Achieving this technical efficiency potential could help provide Taiwan with additional security that it could meet its power needs at a lower level of dependency on imported energy sources. While the percentage of imported energy required would not change, the lower absolute level of demand would reduce the absolute level of dependency. Even in this case, Taiwan year 2020 power consumption per capita would reach today's levels in the United States. The

50. The demand reduction is implemented in the model by reducing the growth rate in the 2005-2020 periods by 0.005 percent annually.

scenario suggests that a minimum investment of US$12 billion in energy-efficiency incentives is warranted in Taiwan. The earlier this investment is made, the more impact it will have in deflecting downward Taiwan's rapid rate of power demand growth.

Low Carbon Emissions Scenario: This scenario tests the effect of imposing carbon emission reduction goals on electric power generation. It uses the higher GDP growth rate assumptions of the original base case. Aggressive environmental standards in this case would include cutting carbon

Table 12: Carbon Emissions (Million Tons)	**2000**	**2005**	**2010**	**2015**	**2020**
Base Case	28	32	41	48	57
Modified Base Case	28	31	38	46	54
Energy Sector Reform Case	28	33	44	56	67
Energy Sector Reform Case, Low Growth	28	33	40	48	57
Energy Efficiency Case	28	33	42	53	63
Energy Efficiency Case, Low Growth	28	33	38	44	47
Low-Carbon Case	28	32	37	43	48
Low-Carbon Case, Low Growth	28	31	34	38	39

dioxide emissions growth from a doubling in 2020 to an increase of 70 percent. In addition, this scenario builds on the energy-efficiency case, but adds US$100 per ton in "taxes" to the cost of emissions of carbon dioxide.[51] It is important to note that the "cost" of this tax is *not* included in the total incremental cost of meeting power demand in the scenario, but is simply a policy tool for effecting changes in technology choice. It should be noted, too, that this is not the average cost of reducing carbon emissions, and is not even an estimate of that cost, but an assumed *marginal* cost. Note that in the modeling, this cost is factored into the cost of power but tax revenues are assumed to be recycled. This outcome could be accomplished by shifting taxes or through a tax and rebate scheme.[52] This change tests the practicality and cost of using non-traditional power supply options to meet power demand in Taiwan, including advanced combined cycle gas turbines, microturbines, fuel cells, geothermal power supply, and wind power. While emissions are reduced relative to the levels in the modified base, market sector reform, and energy-efficiency scenarios, emissions still almost double compared to the current level. This scenario would increase the cost of providing power over the period by US$25 billion compared to the efficiency case (high GNP growth) scenario, but costs would still fall slightly below the high GNP growth base case cost estimate.

Low Carbon Emissions/Revised GDP Scenario: This scenario reduces carbon emissions growth to an increase of "only" 43 percent in 2020 compared to the present. The base and modified base cases

51. This is the cost per ton of carbon.

52. In practice, this effect could be achieved by recycling the tax revenues or using them to offset other, less desirable taxes, such as taxes on labor costs.

result in increases in a doubling of current carbon emissions after two decades. The constraints placed on emissions drive the model to lower carbon alternatives, including renewable energy sources like wind and geothermal, and to LNG-fired plants. The resulting shift away from coal increases the cost of power by only $2 billion compared to the efficiency case/revised GDP scenario, and remains far below either of the base cases.

Conclusions

Taiwan's electric power holds many deep uncertainties that put the economy, security, and natural environment of the island at risk. Technical and policy opportunities, fortunately, can be used to mitigate these risks. Key focal points for policy makers include three areas: demand management, market reform, and technological development.

First, demand management could help reduce some of the profound uncertainty in the future of electric power consumption in Taiwan. The wide differences in two plausible power demand forecasts, resulting from different assumptions about the future of economic growth in Taiwan, make planning difficult and exacerbate the risk to the economy of under- or over-building generating capacity. Energy savings measures can help reduce the range of uncertainty in power demand and could thus reduce risk. Cutting power demand with cost-effective measures can also help reduce environmental impacts, the security risks associated with rapidly growing energy imports, and reduce conflict over expansion of the power supply system. This study suggests that an investment of US$8-10 billion in incentives or other technical measures is justified in Taiwan. Taiwan could use investment tax credits, utility-led loan programs, efficiency standards on air conditioning, consumer lighting, and refrigerators, as well as public information programs to promote efficiency. *It is recommended that the government of Taiwan seriously consider implementing energy-efficiency standards.* High priorities could include air conditioners of all types, refrigerators, and commercial and residential buildings.

Second, market imperfections in Taiwan create unnecessary economic costs and environmental impacts. Two key market distortions could usefully be corrected. Electricity prices in Taiwan are held well below replacement cost, a policy that subsidizes power consumption and environmental degradation. Market reforms should make alternative fuels, notably LNG, cheaper, which would in turn make gas-fired power cheaper than nuclear power. This result should follow from liberalization of LNG imports coupled with long-term contracts. Consequently, Taiwan could produce gas-fired electric power at a wholesale cost of about US$0.046 per kilowatt-hour. Nuclear power, using Taipower cost data, would cost about US$0.051 per kilowatt-hour wholesale. Coal-fired power, though much cheaper at US$0.037 per kilowatt-hour, appears to be somewhat limited due to negative environmental impacts as well as energy import security concerns. Restructuring of the gas and power sectors could make LNG the least-cost fuel choice for Taiwan power generation for the next decade. One useful change would allow Taipower to import LNG directly, as it does coal. *It is recommended that power generators, including Taipower, be permitted to import LNG directly*. It is also recommended that the government of Taiwan undertake a serious review to determine if electric power is underpriced to ensure that environmental pollution is not subsidized and that the future of electric power be better assured.

Third, new technological solutions are needed to resolve Taiwan's power problems. Coal is relatively inexpensive but would greatly increase Taiwan's emissions of greenhouse gases. But nuclear power would become only marginally competitive in Taiwan even with a carbon tax of US$100 per ton. Renewable technologies such as wind, geothermal, and biomass appear to offer only limited contributions over the next two decades. Taiwan possesses a sophisticated scientific and technical community, and safe, relatively non-polluting systems could be developed with appropriate investments in research and development. Of particular interest are distributed power systems using fuel cells or microturbines. The government and people of Taiwan have an opportunity to sponsor and develop new technology solutions, and perhaps to profit by exporting new technologies and services.

Appendix 1:
Selected Power Rates in Taiwan, 1999-2001

Selected TPC Rate Schedules
1-Jun-99

Number	Description	Comment	NT$	US$
I.A.	Low Tension	Summer <110 kWh/month, Non-Commercial	2.20	0.070
I.A.	Low Tension	Summer > 330 kWh/month, Non-Commercial	3.30	0.106
I.A.	Low Tension	Non-Summer > 330 kWh/month, Non-Commer.	2.60	0.083
I.A.	Low Tension	Summer, Commercial	3.30	0.106
I.A.	Low Tension	Non-Summer, Commercial	2.60	$0.083
II.A	High Tension	TOU A, Peak, Summer	1.96	0.063
II.A	High Tension	TOU A, Off-Peak, Non-Summer	0.71	0.023
II.A	High Tension	TOU B, Fixed-Peak, Summer	3.06	0.098
II.A	High Tension	TOU B, Mobile-Peak, Summer	5.36	0.172
II.A	High Tension	TOU B, Off-Peak, Non-Summer	0.65	0.021
II.B	Extra High Tension	TOU A, Peak, Summer	1.95	0.062
II.B	Extra High Tension	TOU B, Fixed-Peak, Summer	3.04	0.097
II.B	Extra High Tension	TOU B, Mobile-Peak, Summer	5.32	0.170
II.B	Extra High Tension	TOU A, Off-Peak, Non-Summer	0.70	0.022
II.B	Extra High Tension	TOU B, Off-Peak, Non-Summer	0.64	0.020

Note: Exchange rate was valid for first half of 2001 at 31.23 NT$/US$.
Source: “Taiwan Power Company Rate Schedules, Taipower Corporation, Taipei, Taiwan, 2001.

Appendix 2:
A Guide to Linear Programming for Power Sector Analysis

Analysts use linear programming (LP) models to optimize combinations of inputs whose values are valid only over specific ranges. For example, power planners and electric utilities use LP models to determine the types of power plants required to meet least-cost power demand over time while meeting limitations in pollution emissions, energy sources, and manufacturing capacity. Models can help planners analyze alternatives, but non-quantitative factors must also be considered in designing real-life systems.

Researchers use two classes of models to analyze energy systems. LP models are often called "bottom-up" models because they contain detailed information about technology and costs. They have rich engineering detail and rely on user input to simulate broader economic conditions. "Top-down" models, on the other hand, begin from a higher level of economic reality by simulating the interaction of supply and demand in the main sectors of an economy. While top-down models have less detailed information about energy technologies and costs, they capture the reality of consumer behavior better than bottom-up models. Some models, like MARKAL-MACRO, try to integrate the economic reality of top-down models with the engineering detail of bottom-up models.

Researchers at Pacific Northwest National Lab created a generic LP model to analyze least-cost power options according to the conditions in specific countries. The model can choose among 17 different types of power plants (coal, petroleum, natural gas, nuclear, hydroelectric, and renewable) to meet power demand. The model divides the country into as many as five regions to capture the variation in energy availability, fuel cost, and environmental limitations. Simulation begins with a base year (2000) and then determines the amount of new capacity from each type of power plant needed to meet demand over 5-year intervals.

After analysts enter technology and cost characteristics of the power plant options, the model calculates the levelized, or life cycle, costs of power generation. Levelized cost analysis accounts for all the costs of building, fueling, operating, and controlling pollution from power systems and spreads them out over the economic life. In this way, the costs of delivering power to users from nuclear plants (with high construction and low fuel costs) can be compared directly with the costs of providing power from combined-cycle plants (low construction costs and high fuel costs). Users also need to enter the power demand over time and regions.

These values are calculated separately according to estimates of economic growth and power demand intensity. The actual linear program will then find the minimum cost combination of power plants needed to meet the demand. Additional constraints can include emission caps on pollutants such as sulfur dioxide, manufacturing limitations for power generation equipment such as nuclear reactors, energy supply limitations such as hydropower capacity, and transmission line characteristics that limit the amount of power that can be sent from one region to another. For a given time period, the LP will choose the cheapest power source available and continue to use that technology until a constraint prevents its use. LP models need expert input to define when constraints are needed to simulate reality.

Source: Jeffrey Logan, Battelle Memorial Institute, Pacific Northwest National Laboratory.

Appendix 3:
Comparison of Taipower Company Power Demand Forecasts, March and September 2001

Year	GDP March Forecast (%)	GDP Sept Forecast (%)	Energy, March Forecast TWH	Energy, Sept Forecast TWH	Peak, March Forecast GW	Peak, Sept Forecast GW
2000	6.0	6.0	143	142	26	26
2001	5.3	4.0	150	148	27	27
2002	5.2	4.0	158	154	29	28
2003	5.2	3.9	165	160	30	29
2004	5.1	3.9	173	165	32	30
2005	5.1	3.8	184	171	33	31
2006	5.0	3.8	190	177	35	32
2007	5.0	3.7	200	183	37	33
2008	4.9	3.7	208	189	38	34
2009	4.9	3.6	217	195	40	36
2010	4.8	3.6	225	201	42	37
2011	4.8	3.5	233	207	43	38
2012	4.7	3.5	243	214	45	39
2013	4.7	3.4	252	220	47	40
2014	4.6	3.4	262	226	49	41
2015	4.6	3.3	272	232	51	42

Source: Taiwan Power Company, March and September 2001.

Appendix 4: Sensitivity Tests

Sensitivity tests were run to determine the relative importance of key assumptions. Three of these deserve special mention. First, a test was run to measure the impact of removing the constraint imposed to reflect current Taiwan energy policy of limiting the supply of a single fuel type to less than half the island's power supply. When the modified base case was rerun with that constraint removed, the share of power supplied by coal increased from 50 percent in the modified base case as reported to 62 percent. The total incremental cost of the scenario dropped from $107 billion to $76 billion. More results are provided in the following table:

Second, a test was run to assess the potential for biomass fuel for power generation. A constraint was

Modified Base Case, Unconstrained					
Coal	19	20	31	41	54
LNG and Oil	10	14	19	26	26
Nuclear	5	8	5	3	3
Hydro & Renewable	4	4	5	5	5
Total	39	47	60	75	87

imposed in all reported cases to limit biomass fuel essentially to zero supply because most environmental and electric power experts advised that due to Taiwan's mountainous terrain and sharp competition for land that biomass fuel would not be practical. Removing that constraint, however, in the low-carbon, low-economic growth scenario permitted biomass-fired combined cycle plants to capture 15 percent of the power generation market, or about 12 GW in that scenario. More results are provided in the following table:

Low-Carbon Case, Low Growth, Unconstrained Renewables					
Coal	19	29	31	34	34
LNG and Oil	10	10	14	20	26
Nuclear	5	5	5	3	3
Hydro & Renewable	4	6	11	16	19
Total	39	50	60	72	82

NOTE: Peaking units added at blue.

Third, a series of tests was run on the effect of reducing the discount rate assumption below the 10 percent level applied–appropriately, we believe–in all cases. In the sensitivity tests, the most notable result was that nuclear power becomes competitive with LNG-fired combined cycle power generation when the discount rate is dropped as low as 6.5 percent. The results for that discount rate are provided in the following table:

System (with a 6.5% discount rate)	**$/kWh**
Coal with flue gas desulfurization	0.0364
Integrated Gasification Combined Cycle	0.0455
Combined Cycle-LNG	0.0474
Nuclear	0.0455