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POWER SUPPLY EXPANSION AND THE NUCLEAR OPTION IN POLAND

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Acronyms and Abbreviations

CHP	Combined heat and power or cogeneration
CIE	Centrum Informatyki Egergetyki, Polish Energy Information Center
DSM	Demand-side management
LDC	Load duration curve
ICEM	Iterative Cost Effectiveness Method
IEA	International Energy Agency
ITRE	Iterative Test for for Resource Effectiveness
OECD	Organization for Economic Cooperation and Development
PPGCo	Polish Power Grid Company
VPL	Verbund-Plan GmbH Consulting Engineers

Abstract

Poland is in the process of liberalizing and modernizing its electric power system. Given its heavy reliance on coal and a consequent history of often severe environmental externalities associated with power production, the nature of capacity expansion in Poland has important environmental and social implications. To better understand capacity expansion in Poland, we constructed a data set of the Polish power sector for use with the Elfin capacity expansion planning model. Using Elfin, we derived four scenarios and several sensitivities for new generating capacity construction. These scenarios simulate choices among several generic generating technologies made to achieve the lowest overall net present cost of operating the power system through 2015. We find that natural gas is a highly desirable fuel for future power generation in Poland, but primarily as a peaking resource. As the current system is inflexible and peaking capacity appears to be the most pressing need, this result is not surprising. However, when nuclear power is included as a generation option, natural gas is less desirable than the Polish Power Grid Company (PPGCo) has suggested, and, despite the PPGCo's claims to the contrary, nuclear power cannot be ruled out in Poland on economic grounds alone. In the unconstrained Elfin scenarios, using PPGCo assumptions, nuclear power is attractive, especially after 2010. The attractiveness of nuclear generation proves sensitive to certain input variables, however, notably fixed operating and maintenance cost, and possible carbon taxes. Moreover, we find that the effectiveness of conservation efforts designed to reduce airborne emissions is limited under scenarios in which nuclear generation is adopted.

CHAPTER 1

Introduction

1.1 Study Goal

Current power generation in Poland is heavily dependent on coal (OECD 1995). About 55% of Poland's annual generation of approximately 138 TWh currently comes from burning bituminous or hard coal and a further 42% from lignite or brown coal. Hard coal generation capacity totals almost 12 GW, and lignite capacity over 7 GW. Roughly 20% of all generating capacity, 5.6 GW, is combined heat and power (CHP), or cogeneration, plant, which also provides district heating. Poland has no active nuclear capacity, limited natural gas resources, and limited quantified renewable potential (Baguenier 1994). Consequently, while power generation relies almost exclusively on domestic energy sources, the risk of supply interruption, from strikes for example, remains high, and the environmental cost of coal combustion is great. Policy on the future of power generation in Poland revolves around the fate of existing coal and lignite generating capacity and what replaces archaic plants upon decommissioning. New coal-fired capacity could be more environmentally benign than the existing stock but residual environmental problems would persist, notably from CO_2 emissions. While natural gas supplies from Russia currently appear plentiful, the specter of heavy dependency on imported fuel creates unease in Poland, particularly since mid-winter peak power generation requirements coincide with strong gas demand from Western Europe, and the need to substitute natural gas for coal in building heating is seen as a major priority to improve urban air quality. *Prima facie*, therefore, nuclear power may hold some appeal for Poland, in spite of the current absence of any nuclear industry.

The goal of this work is to establish power supply modeling capability for Poland, and to derive minimum-cost capacity expansion plans. These plans can help answer several policy questions, but the one of primary interest here is how economically attractive is nuclear power.

1.2 The Elfin Model and the Poland Data Set

The expansion planning model chosen for this analysis was Elfin, a proprietary product of the Environmental Defense Fund of Oakland, CA (EDF 1995). Data was provided by the Polish Power Grid Company (PPGCo) from its seminal study completed with Verbund-Plan GmbH Consulting Engineers of Klagenfurt, Austria, (VPL) using the WASP III model (PPGCo 1994a, 1994b). The basic data set, fully reported by PPGCo in its *Scenarios* report (PPGCo 1994a), is enhanced considerably by this work. Using modified PPGCo assumptions, notably by the inclusion of nuclear power, Elfin found minimum cost expansion plans under four scenarios, labeled A-D. Scenario A is a constrained scenario intended to parallel PPGCo's *Stagnation Scenario* by fixing the construction level of natural gas-fired capacity. In Scenario

B, this natural gas requirement is dropped. Scenarios C and D mimic A and B, but with the added assumption in both that demand-side management (DSM) programs are introduced across Poland.

As the work described in this paper represents a first effort at modeling the Polish power sector using Elfin, the issue of deriving optimal rehabilitation schedules was not broached, and only the question of new technology choice is addressed here. The issue of rehabilitation was handled by adopting a rehabilitation strategy developed by VPL (PPGCo 1994b, page 4-13).

1.3 The Polish Pool

As in all former eastern block countries, and indeed in most OECD countries, the future structure of the Polish electric utility industry is uncertain. Current policy calls for a two-stage introduction of a competitive pool, beginning in 1998 (IEA 1995). While models such as Elfin are based on the traditional paradigm of centralized dispatch of power system operations and centralized investment decision making for new plant, there are sound reasons to believe that Elfin results closely approximate the outcome of a competitive pool with individual investment decision making. Central dispatch in a pool system applies the same cost-minimizing principals as traditional dispatch, and—under competitive conditions—private profit maximizing and social cost minimizing are behaviorally identical (Kirshner 1996). Note also that, in the analysis conducted here, no account is taken of the need to recover fixed investment costs via the revenue stream provided to generators from pool prices. Luckily, the high load factors of Poland's electricity demand serve to minimize this error because new capacity will enjoy relatively high capacity factors and have a good chance of recovering fixed costs.

Method and Data

2.1 Marginal Cost Estimation Using the Load Duration Curve Method

Elfin uses standard load duration curve (LDC) methods to calculate marginal cost and other key results of electricity production simulation. Figure 1 shows the chronological load curve for a typical December week, and Figure 2 shows how the overall level of generation varies throughout the year. An LDC is simply a reordering of chronological load data into the form of Figure 3, in which the x-axis shows how many hours the load was equal to, or greater than, the power level, shown on the y-axis. The LDC allows the use of powerful mathematics to simulate dispatch in an accurate yet rapid enough manner to permit the extensive searching required to identify low-cost expansion plans. Figure 3 shows schematically how Elfin uses the LDC to simulate the simple economic dispatch of Polish power plants to meet this load. In the figure, the available assets are sorted by fuel cost and are dispatched as single blocks by fuel. The capacities, that is the heights of the blocks, represent the approximate amounts of each capacity type available during this period, and the shaded areas show an approximation to an economic dispatch, where darker shading implies higher cost. In other words, the areas of the shaded sections show the output coming from each resource.

Since in a well-functioning pool generators bid their marginal costs, and the marginal cost of the last generator dispatched sets the pool price, estimation of marginal cost is of particular interest. Coal usually serves as the last resource dispatched, that is, coal is usually marginal. In fact, throughout the 148 hours to the right of the vertical line in Figure 3, coal is the marginal fuel. The final resource to be dispatched is pump storage, which is the marginal generation source for the remaining 20 hours. Marginal cost during the period, then can be estimated as the weighted sum of the marginal cost of coal and pump storage. Since water must be pumped into storage using coal-fired generation, the overall pattern of dispatch results in coal in one form or another always being the marginal fuel. Therefore, marginal costs can be expected to vary rather little in Poland, and pool prices can be expected to be quite stable.

Finally, to complete the discussion of marginal costs, it is illuminating to look at some actual Elfin marginal cost results. Table 1 shows actual Elfin output for 2000.

Figure 1. Electrical Load on the Polish Power Grid (Typical Week of December 1993)

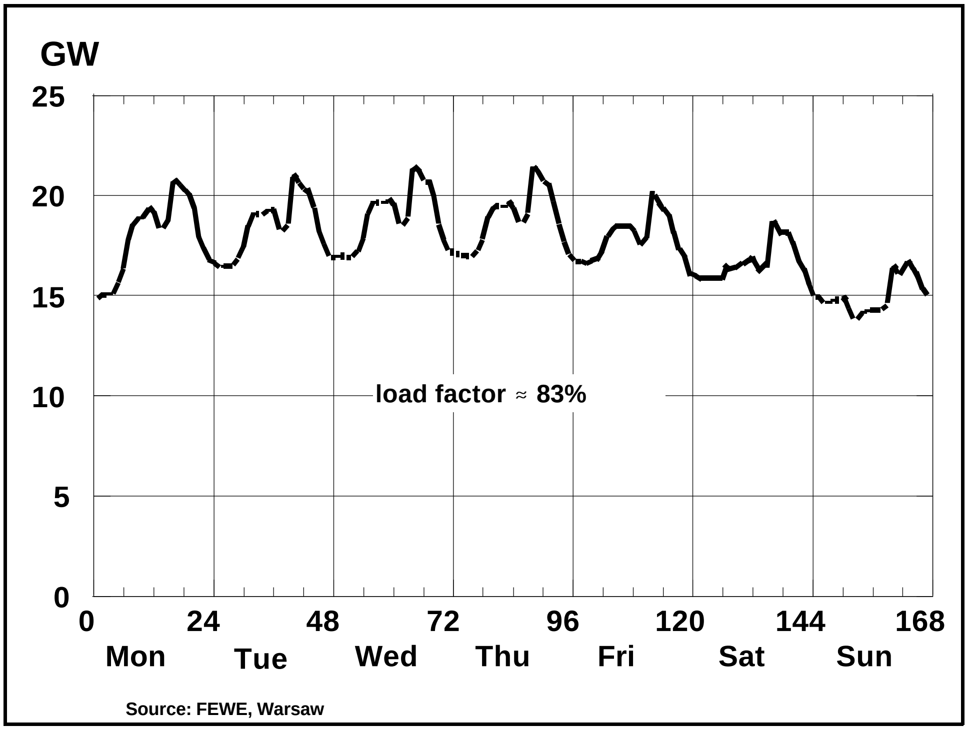


Figure 2. Estimated 1993 Monthly Electricity Generation

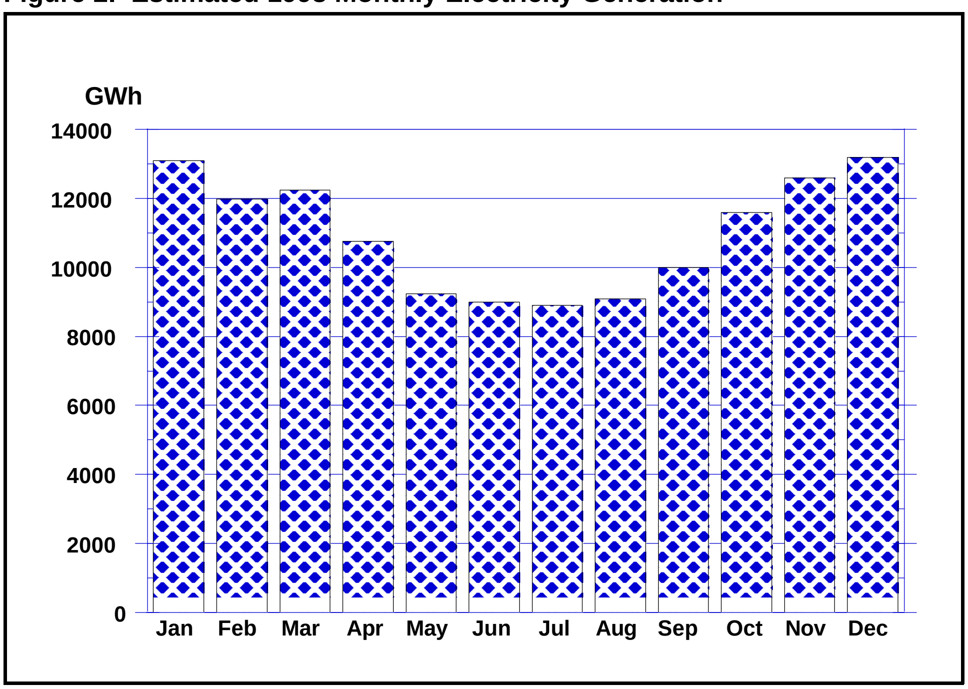


Figure 3. PPGCo System Load Duration Curve (Typical Week of December 1993)

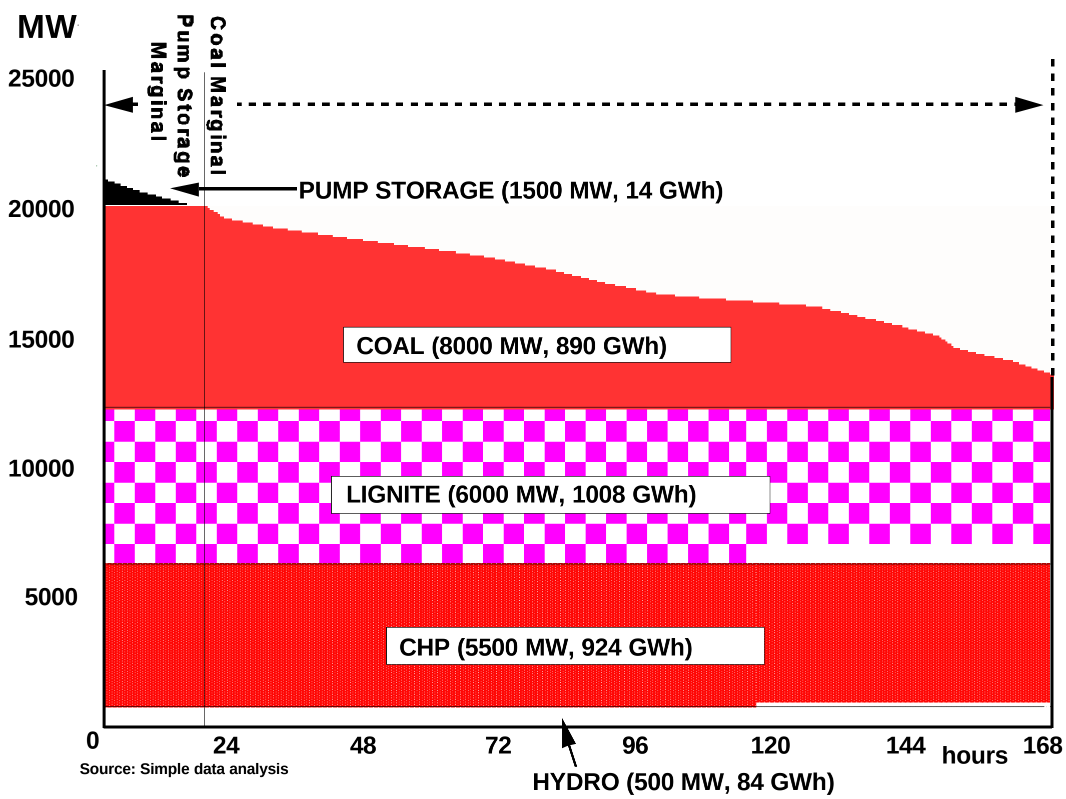


Table 1. Base Case Marginal Cost Results for 2000 (U.S. 1993$/MWh)

Time Periods	Annual	Winter	Summer
Weekdays (06:00-18:00, M-F)	$28.90	$39.20	$14.60
Weeknights (18:00-06:00, M-F)	$24.10	$24.10	$17.00
Weekends (18:00F-06:00M)	$13.90	$13.70	$14.30
Average	$25.00	$31.90	$15.40

2.2 ICEM-ITRE

Elfin was chosen for this work for several reasons. First, it accurately simulates dispatch because units are dispatched by blocks, rather than by stations or groups. Second, Elfin has a pump storage algorithm, which is important for modeling a Polish system that contains almost 1.5 GW of storage capacity. Third, the dynamic programming algorithm used in most planning models, while technically capable of finding a true optimal plan, is less well suited to problems where the number of alternative choices is high, as in Poland. In contrast, Elfin searches using the Iterative Cost Effectiveness Methodology-Iterative Test for Resource Evaluation (ICEM-ITRE) method (Peña 1993, Logan 1991). This approach, while unlikely to find the perfect theoretical optimum plan, can find a reasonable least-cost plan with less need for judicious and honest constraint setting on the part of the modeler and in much less computation time than dynamic programming requires for a similar level of dispatch accuracy. Nonetheless, typical simulations, such as the scenarios described here, require several days of computation on a fast PC.

As its name suggests, ICEM-ITRE is typically used to derive an expansion plan in two stages. First a base plan is found using the Iterative Cost Effectiveness Method (ICEM). ICEM chooses new resource additions by a simple rule-of-thumb, two-test approach. If a new resource is both cost effective in its first year and has a positive lifetime benefit-cost ratio, it is built. Then, in the second stage, the Iterative Test for Resource Evaluation (ITRE) searches for incremental improvements to the ICEM plan (EDF 1995). All possible additions to and subtractions from the plan of construction alternatives are ranked and changes are made to the plan until no more cost reducing changes can be found.

2.3 Electricity Demand and the System Load Shape

Again, Figure 1 shows the system load curve for a typical week. The load has two notable features. First, the diurnal shape is bimodal, exhibiting both late morning and late afternoon peaks; and second, weekly load factors are a high 83 %. Summertime loads are similarly shaped, and the annual load factor is 66.5 %, with assumed line losses of 7.5 %.

The demand forecast used is a simplified version of the stagnation scenario developed by PPGCo, which, despite its name, forecasts rapid energy and peak demand growth. All four scenarios used a simple demand growth rate of 2.671 %/a, a simple peak demand growth rate of 2.561 %/a, and minimum load growth rate of 2.682 %/a, which allow the starting point of actual 1993 data and the end points, that is 2015, of the forecast to match the stagnation scenario.

One obvious problem with this overall forecast is its failure to represent the structural changes that can be expected in the Polish economy over the next 20 years. Using the stagnation scenario assumptions, the extraordinary load factors of the Polish system are not only maintained but increase slightly, from 66.5 to 68.5 %. Some exploratory analysis showed that results are not highly sensitive to the minimum load growth assumption, a key determinant of capacity factor. Nonetheless, a more complete end use based load shape forecasting effort is urgently needed, given that the structure of demand is likely to change significantly (Meyers 1993 and 1994).

2.4 Fuel Prices

Table 2 shows the base price of fuels assumed for 1993, and the real rates of price escalation used for all four scenarios. The average rates of price increase over the period 1992-2020 are adopted as a simple escalation rate and applied throughout the period.

Table 2. Base Case Fuel Price Escalation Forecast

Fuel	Price (1993$/GJ)	Real Price Escalation (%/a)
Domestic Coal	by formula	2.3%
Lignite - Bełachów	$1.11	2.3%
Lignite - other	$1.51	2.3%
Natural Gas	$4.35	1.7%
Fuel Rods	$0.60	0.5%

Four points should be noted here. First, despite the low current price of lignite, its price is forecast to grow as fast as that of domestic coal. In other words, the relative attractiveness of these two fuels is fixed. In contrast to PPGCo's work, two types of lignite are assumed, one representing the current lignite reserves used at Bełachów and a second more expensive type which must be used at any new lignite facilities. Second, the price of natural gas used is higher than PPGCo's to simulate the cost of maintaining gas in storage in order to avoid wintertime supply curtailments. Also, gas prices, while high in 1993, escalate more slowly than solid fuels, making gas an increasingly attractive fuel as time progresses. Third, in contrast to the generic price of coal used by PPGCo, the formula shown in Figure 4 is used to estimate coal costs at each station using CIE coal quality data (CIE 1994).

Figure 4. Coal Pricing Formula for Polish Steam Coal

$$P = Pm\left[\frac{Q}{25.1208} - \frac{S-1}{10} - \frac{A-12}{100}\right]$$

where,	P	= price of coal in $/t
	Pm	= marker coal price (32 $/t)
	Q	= calorific value in GJ/t
	S	= sulfur content in %
	A	= ash content in %

Source: IEA 1995, p.1003.

2.5 Plant Operating Data

The operating data implemented in Elfin comes almost entirely from the PPGCo's Scenarios report. These data describe the large thermal stations which form the bulk of the Polish power system. Where the Scenarios data set is unclear, data from Szpunar, *et al*. (1990) have been used, together, of course, with some educated guesses.

Unfortunately, the Scenarios data provide no information on the startup flexibility of thermal units and minimal information on other engineering operating constraints. This could be a significant factor because so much of the capacity is coal or lignite and so much is old. It is reasonable to assume that these plants are not flexible in their operations, and, if they are used at all during any week, they must be kept running all week.

Also missing from the Scenarios report is data on hydroelectric power in Poland. The hydro data implemented in Elfin comes primarily from an original Elfin file provided by the Polish Federation for Energy Efficiency (FEWE) and from Szpunar, *et al*. (1990). Additional information was taken from the CIE energy balances for Poland (CIE 1993c). The hydro units are represented as ten run-of-river units, the nine largest actual stations, plus an *Other Hydro* category, for a total of 534 MW. Since no seasonal data was available and the dispatch control systems at Polish hydro stations are known to be rudimentary, all hydro is treated as a flat non-dispatchable run-of-river resource. Poland has considerable pump storage capacity, almost 1500 MW, dispersed at several sites. These assets were represented as three pump storage facilities.

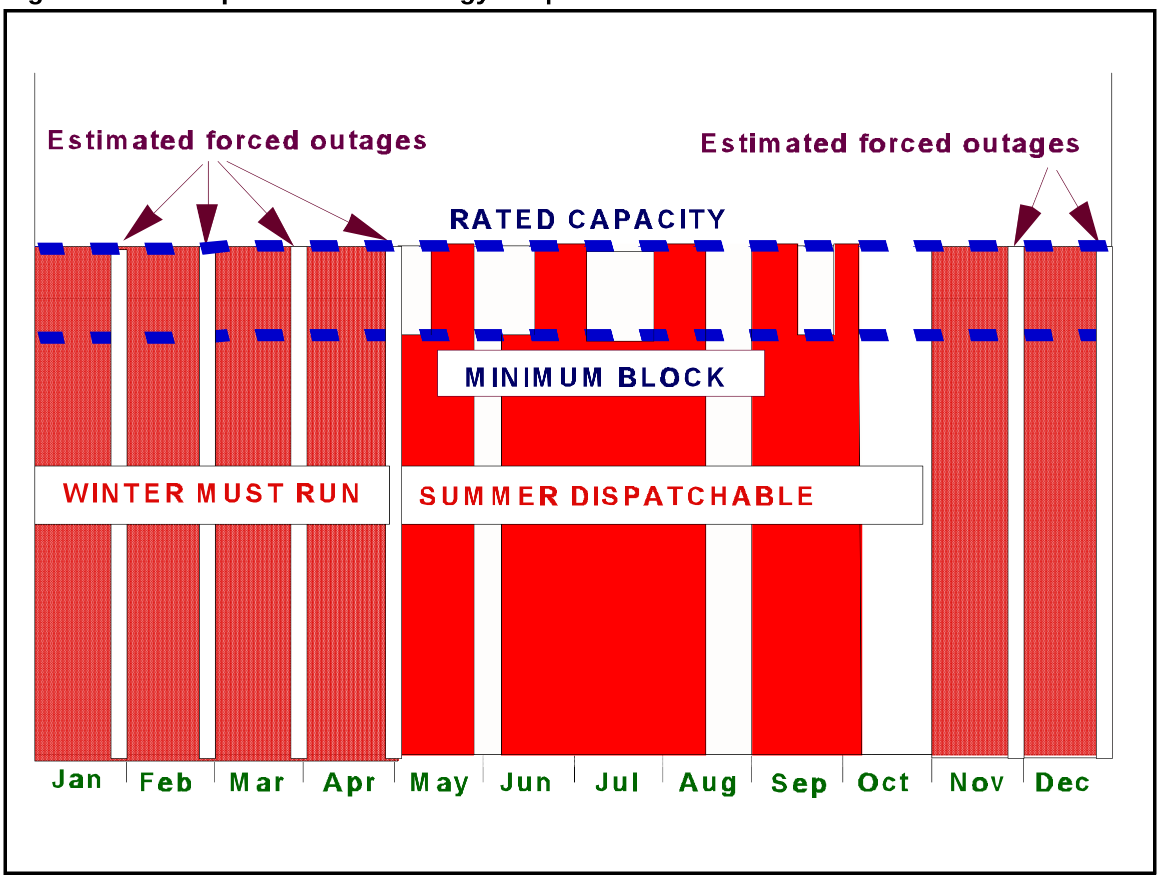
Emissions factors for six pollutants were calculated from CIE data and incorporated into the data set, under the assumption that all stations comply with proposed emission limits (CIE 1994b, IEA 1995). The emissions fees imposed by recent laws were also incorporated as real costs that appear in results as production costs.

2.6 Combined Heat and Power (Cogeneration)

There is no established method in the literature for representing CHP in production cost modeling, and a totally original approach, demonstrated in Figure 5, is used here. The CHP capacity is represented as eleven stations, the ten largest plus an *other CHP* station. Each CHP unit is represented in Elfin twice, once for the winter, or heating season, and separately for the summer, or condensing season. The CHP units are treated as must-run resources in winter, that is, they are non-dispatchable and operate with heat rates of 7,500 kJ/kWh. Based on historic energy output, a heating season was calculated for each of the units, but because a season must be an even number of months, the exact energy required cannot be obtained by this maneuver alone.

Therefore, a forced outage rate was estimated for each unit that reduced its energy output to the range desired. In summer, all CHP units are dispatchable at a heat rate of 12,000 kJ/kWh.

Figure 5. Assumption on CHP Energy Output



2.7 Generic Expansion Alternatives

The heart of the capacity expansion problem is the establishment of generic generation expansion options. These must be few in number, to achieve computation feasibility, and yet must realistically represent the technological alternatives available. Table 3 shows the options used for all scenarios. The generic units, coal through nuclear, are the ones used by PPGCo. The two final options, Opole and Turów, are refurbishments of existing plants that were taken as given by PPGCo, but were treated as expansion options in this study.

Table 3. Generic Expansion Alternatives

Fuel	Capacity (MW)	Capital Cost (1993$/kW)	Technology
Coal	600	$1,412	w/ desulfurization
Lignite	360	$1,680	w/ desulfurization
Gas	150	$400	gas turbine
Gas	430	$650	combined cycle
Nuclear	600	$1,800	passive safe
Opole (coal)	360	$1,415	repower w/ desulfurization
Turów (lignite)	240	$690	repower w/ desulfurization

Results

3.1 Scenario A: Constrained, No DSM

The purpose of the constrained Scenario A is to parallel PPGCo's stagnation scenario with the assumption changes described above and the inclusion of nuclear. The number of gas turbines and combined cycles added is fixed at the levels chosen by PPGCo. Figure 6 shows cumulative new construction for the constrained scenario expansion plan. In the figure, the uppermost two resources, *gas turbine* and *combined cycle*, are gas fired, the central two, *coal* and *Opole*, are coal fired, and the lower two, *lignite* and *Turów*, are lignite fired. The notable results are:

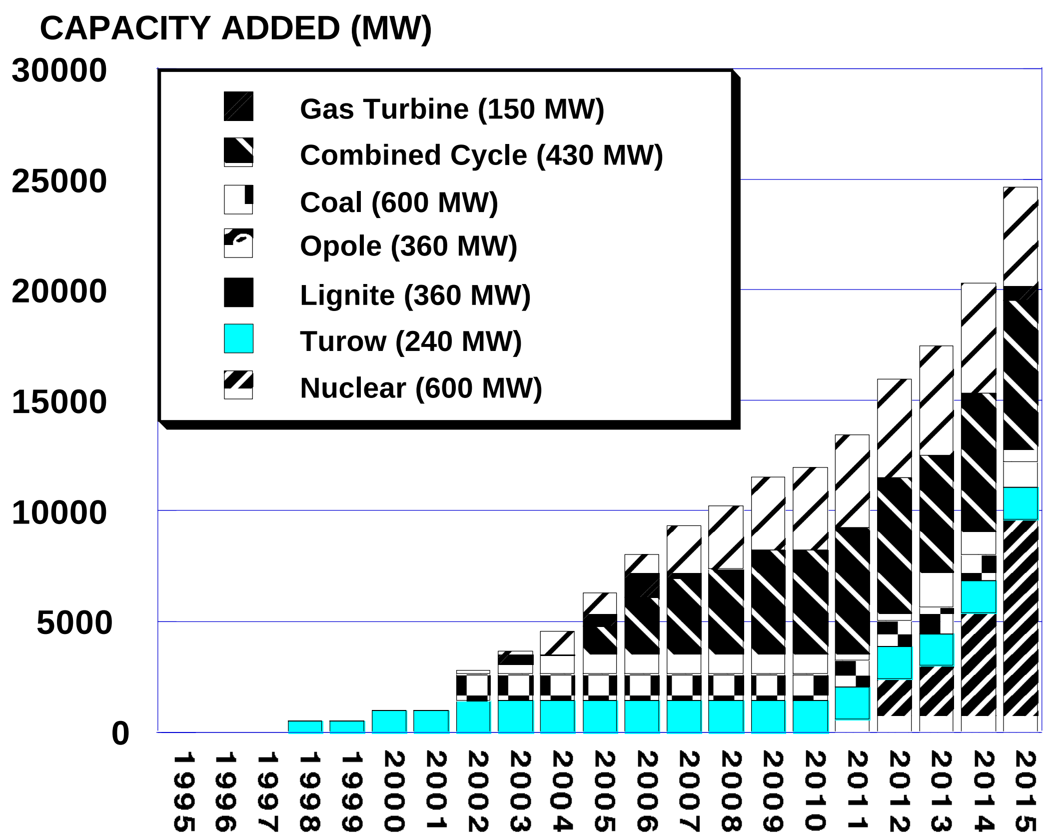
(1) no new lignite capacity is chosen, nor is the Opole repower;
(2) the fixed natural gas fired generation additions provide almost exactly half of all the new capacity;
(3) while additions to 2003 are primarily coal and lignite, gas additions dominate from 2003 on, and
(4) 16 nuclear units are chosen, so that after 2012, this plan diverges substantially from PPGCo's results, in which nuclear power is not an option.

These results indicate that, while the repower facility at Turów is attractive to Elfin and some coal capacity is built, nuclear almost completely drives out coal towards the end of the period. This result calls into question PPGCo's claim that nuclear power cannot be economic in Poland (PPGCo 1994b, page 8-26).

3.2 Scenario B: Unconstrained, No DSM

In Scenario B, shown in Figure 7, all constraints on plant construction are removed. Coal and lignite are completely driven out of the expansion plan, and Opole appears with one unit only. Even more nuclear capacity is added in the later years of the simulation, reducing the number of combined cycle units chosen to one. Most surprising is the degree to which Elfin favors combustion turbines in the early years, in stark contrast to the constrained case, demanding 20 units by 2000 and a remarkable 73 units by the end of the planning horizon. Notice the 7-year period beginning in 1998, in which Elfin builds only gas turbines. Since gas turbines tend to run only during peak periods, the total amount of fuel they burn can be small. For this reason, the total gas consumption of Scenario B is about 3×10^9 m^3/a by 2015, compared to about 7.5 for Scenario A. In other words, import gas dependency is far lower under Scenario B, and the cost of gas storage has been accounted for. Other analyses of Polish power generation have proposed far higher levels of natural gas consumption than these, often in the range of 10×10^9 m^3/a. Equally remarkable is the attraction of nuclear, which dominates construction in the latter years, with a total of 20 reactors being built.

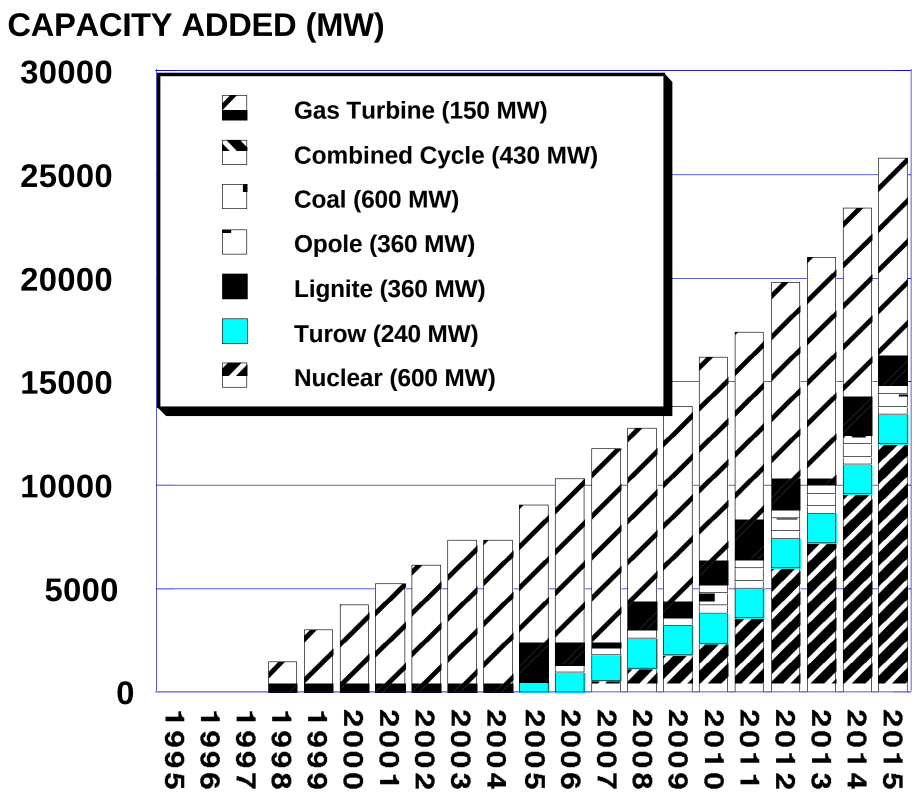
Figure 6. Scenario A (Constrained, No-DSM) Expansion Plan



Source: Elfin simulation

While the heat rate used for gas turbines is high (12,000 kJ/kWh), as is the assumed cost of gas, the attractiveness of gas turbines is not totally unexpected because gas turbines have low capital costs, gas prices rise slowly, and existing capacity is highly inflexible. While the first two reasons are self-explanatory, the last requires additional clarification. An overwhelming share of the Polish system consists of inflexible coal and lignite assets. This inflexibility raises costs, even if the fuel itself is not expensive. A resource such as a gas turbine that can be started and stopped instantly can prove cheap even if its operating fuel cost is high. In a sense, gas turbines allow a system such as Poland's to make better use of the cheap resources that it already has in abundance. Another attraction of quick start assets is their reliability, which contrasts with the high forced outage rates of lignite and coal units that limit their value in meeting overall load.

Figure 7. Scenario B (Unconstrained, No-DSM) Expansion Plan



Source: Elfin simulation

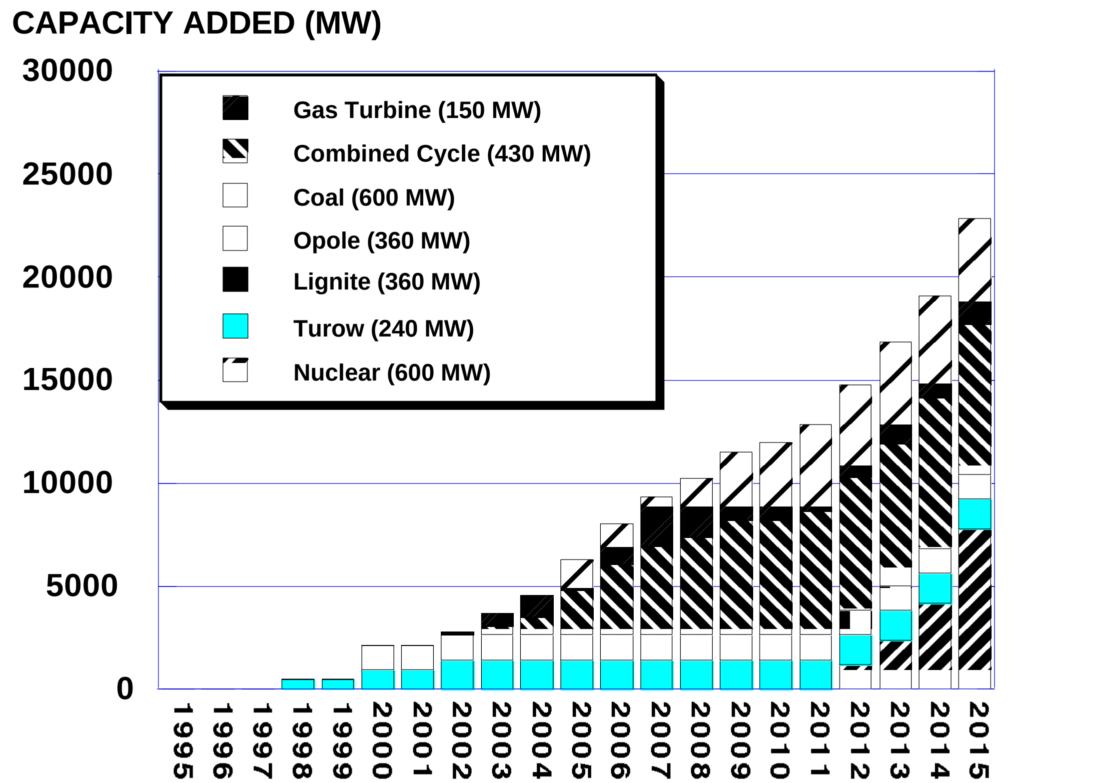
Another interesting aspect of Scenario B is the *overbuilding* that Elfin recommends. The reserve margin of the whole system never falls below 20% after 1997 in this scenario, whereas it never exceeds 17% in the constrained case. This result demonstrates an important distinction between the purely economic logic of Elfin versus methods that impose a hard reserve margin constraint on the result. Elfin chooses capacity additions in a purely economic fashion to minimize net present cost, trading off the costs of additional capacity against the costs of unserved demand. In Scenario B, costs are lowered by building beyond typical engineering reserve margin requirements based on arbitrary reliability criteria.

3.3 Scenario C: Constrained, With DSM

In Scenario C, shown in Figure 8, as in Scenario A, construction constraints exist but DSM programs are initiated across Poland. These programs were developed as cost-effective conservation investments for Warsaw and here are assumed to be applied across Poland (SCRI 1996). The net result of these programs is an increasing reduction in bus bar load relative to Scenario A that, by 2015, reaches an energy demand reduction of 4%, and reductions in peak and minimum load of about 2%.

The plan chosen by Elfin in C differs from A in that the number of nuclear units built falls from 16 to 13. Elfin's decision to reduce construction of baseload resources over peaking ones reflects the high load factor of the DSM measures selected.

Figure 8. Scenario C (Constrained, with DSM) Expansion Plan

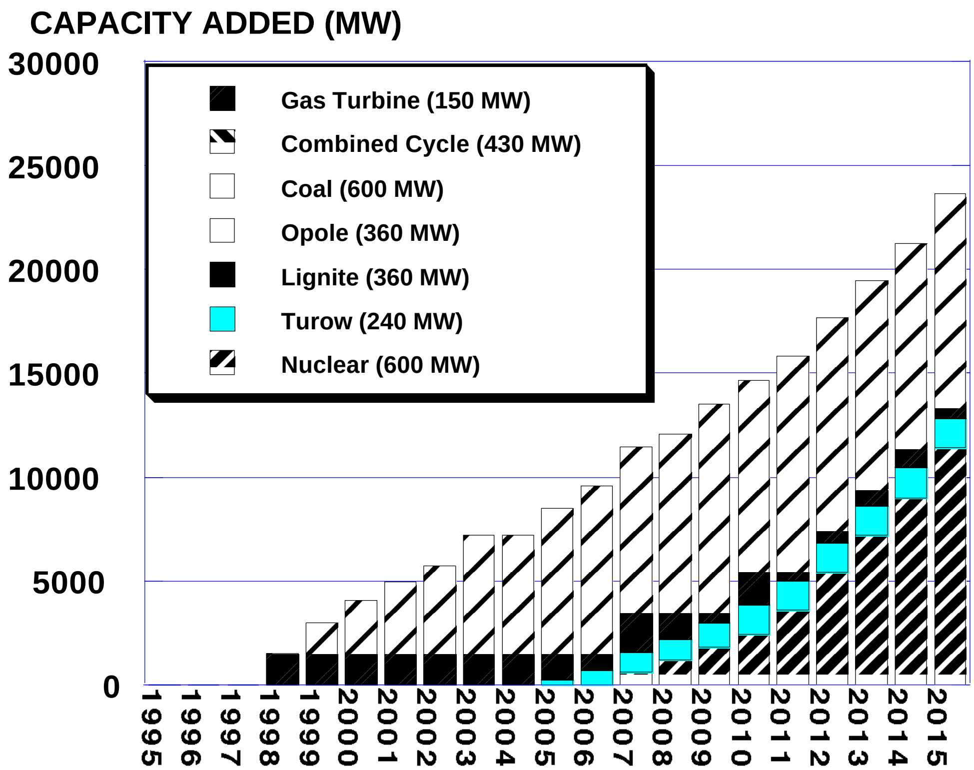


Source: Elfin simulation

3.4 Scenario D: Unconstrained, With DSM

As in scenario B, no constraints are placed on construction in Scenario D, shown in Figure 9. Further, DSM programs are initiated across Poland on the same level as in Scenario C. The key difference in this scenario, relative to B, is that the coal and combined cycle plants are eliminated entirely and less nuclear power is built.

Figure 9. Scenario D (Unconstrained, with DSM) Expansion Plan

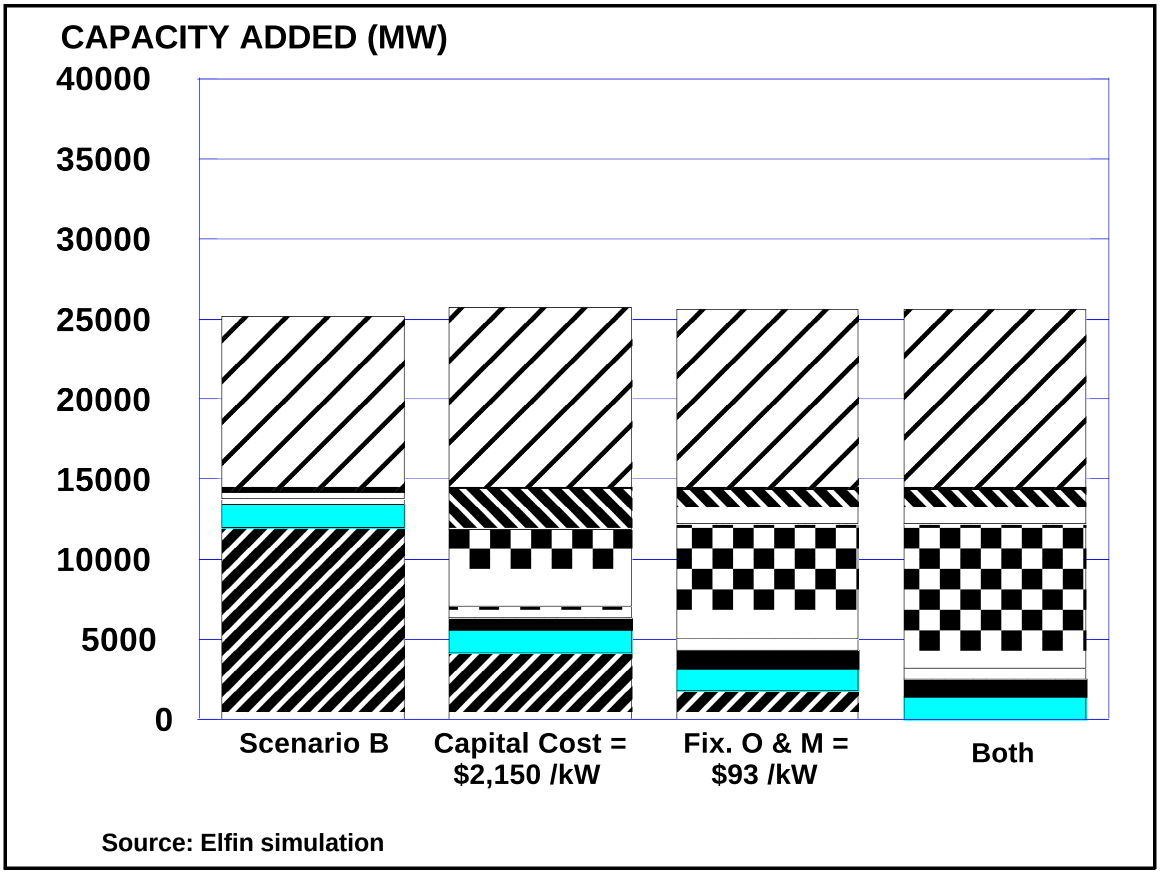


Source: Elfin simulation

Nuclear Sensitivities

The results above show that nuclear power may well be economically viable in Poland. Since this was such an interesting and unexpected result, several sensitivity assessments were conducted. These sensitivities are shown in Figures 10 and 11. In both figures, the legend has been removed to improve clarity, but shade patterns are identical to those used in Figures 6-9.

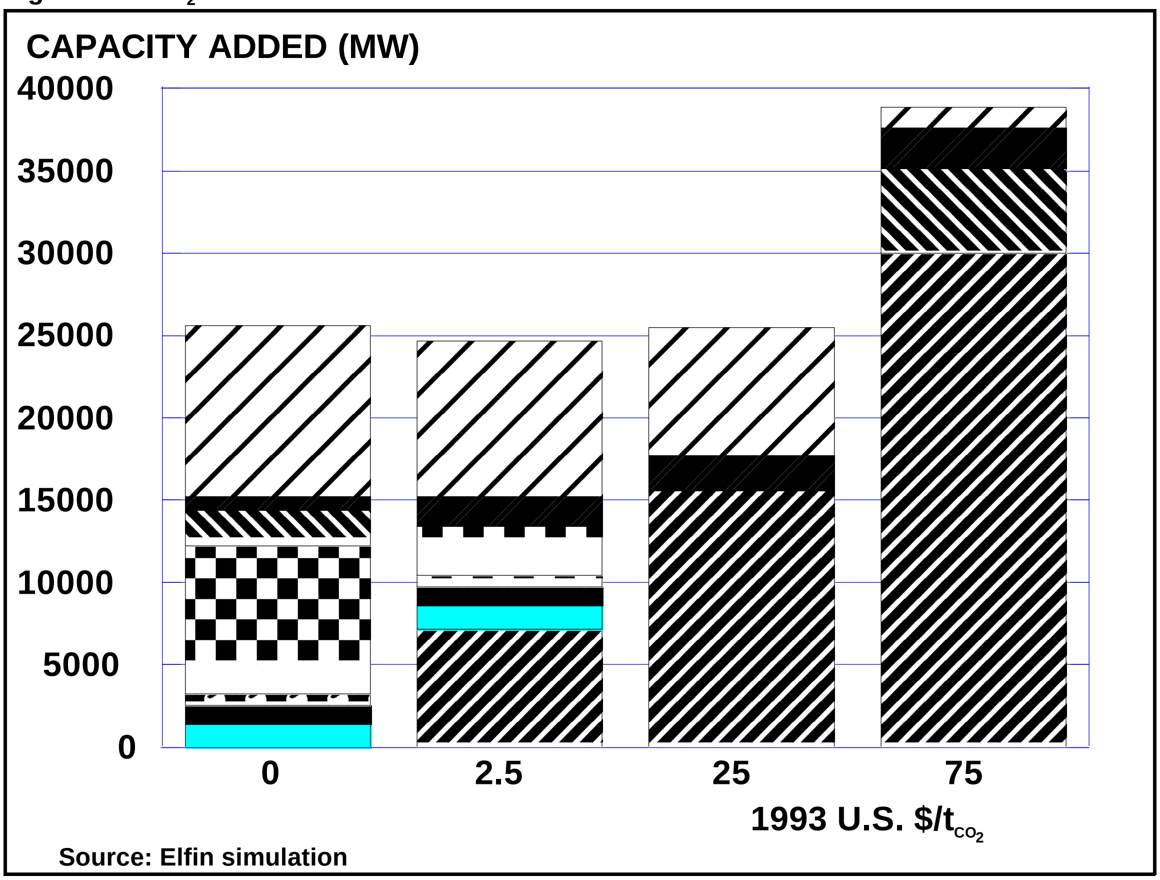
Figure 10. Nuclear Cost Sensitivities



First, it was noted that the cost assumptions of the PPGCo are low compared to typical U.S. assumptions, so they are replaced by some high end American values. As shown by the second bar of Figure 10, increasing the initial capital cost from PPGCo's assumption of 1800 $/kW to 2150, lowers the number of reactors built from 20 to seven. Further, as shown by the third bar, increasing the fixed operating and maintenance cost to 93 $/kW a from the PPGCo assumption of 35 reduces the number built to three. As shown by the right-hand bar, if both these changes are made, nuclear is entirely eliminated from the expansion plan.

Next, turning to the CO_2 tax sensitivities shown in Figure 11, the left-hand bar is identical to the right-hand bar of Figure 10. That is, nuclear power has been eliminated by raising the cost assumptions as described above. In the other bars, however, an increasing CO_2 tax is imposed. Even at the low level of 2.5 $\$/t_{CO2}$ nuclear reappears, and at a tax rate of \$25 nuclear returns to total baseload dominance. Finally, at tax rates above \$50, *excess capacity* is built; that is, the total bar grows. This reflects the fact that eventually thermal plant is duplicated by CO_2-free nuclear power. Similarly, the unfavorable heat rate of gas turbines becomes a burden and they are replaced by combined cycles. It must be emphasized, however, that the sensitivity analysis shown in Figure 11 does not seek to attach costs to nuclear waste disposal and other environmental externalities associated with nuclear power. As such, the analysis inherently favors nuclear power relative to the taxed carbon producing technologies.

Figure 11. CO_2 Tax Sensitivities



Economic and Environmental Implications and General Conclusions

5.1 Cost Analysis

Table 4 summarizes the cost results for the four scenarios described. The right-hand column shows the total net present direct cost of each scenario, which is the ultimate bottom line. This total represents the net present cost of running the Polish power system through the end of the planning horizon, 2015, plus a ten-year extension period. Remember that emissions fees are included in production cost and that no externality values are imposed.

Table 4. Cost Summary by Scenario (millions of 1993 U.S.$)

Scenario	Production	Shortage	Fixed O&M	Capital	TOTAL
Case A	$27,839	$1,206	$4,739	$8,077	$41,860
Case B	$25,842	$558	$4,822	$8,454	$39,675
Case C	$27,399	$1,200	$4,678	$7,685	$40,961
Case D	$25,291	$599	$4,777	$8,084	$38,751

The key difference between Scenarios A and B is the restriction on gas unit construction in A. Freed of this constraint, Elfin finds a 5% lower cost solution in Scenario B. Comparing the details of A and B, it is clear that the major gain comes from lower production cost, as cheap nuclear fuel replaces gas. Conversely, nuclear has higher operating and capital costs and these totals rise. However, in Scenario B a major savings also come via lower shortage costs, earned by Elfin's desire to build more new capacity. Scenarios C and D reflect their non-DSM counterparts, but reduce costs by a further 2% each. The fact that costs are reduced less proportionately than output, 4%, again reflects the baseload character of the DSM programs selected.

5.2 Environmental Results

Table 5 presents total emissions and percent change in emissions for six major airborne pollutants in each of the four scenarios. No very large emissions reductions are made, though some scenarios come out better that others in certain categories. In both of the unconstrained scenarios, B and D, CO_2 and NO_x emissions are noticeably lower than in the constrained scenarios, A and C, due to greater nuclear generation. In contrast, the constrained cases have lower SO_2 emissions than the unconstrained cases, because gas is favored over coal and lignite. As to the environmental effects of DSM, Scenario D shows generally lower emissions than its non-DSM equivalent, Scenario B. This pattern does not appear, however, in Scenarios A and C. This seeming anomaly can be explained by the fact that in Scenario C, the constrained DSM case, the units that are *not* built due to DSM savings are nuclear units. Hence, even though generation is actually higher in Scenario A than in Scenario C, the added capacity in Scenario A is all nuclear and does not produce the airborne emissions reported here.

Table 5. Emissions in 2015 (millions of metric tons per year - Mt/a)

Scenario	PM	SO_2	NO_x	CO_2	CO	Methane
Case A	0.162	0.500	0.254	166	0.025	0.001
Case B	0.166	0.514	0.249	156	0.026	0.001
Case C	0.163	0.504	0.257	168	0.025	0.001
Case D	0.162	0.508	0.242	152	0.026	0.001

Heavy metal emissions were also estimated. The results show that the Polish power sector will continue to be a major emitter of certain heavy metals in 2015, notably arsenic (As), cadmium (Cd), and nickel (Ni). These results were estimated using a simple equation where the rate of emission of a given metal in metric tons per year is a function of the emission factor of the metal in grams of emission per metric ton of fuel, and various assumed emissions factors by generation facility type for the particulate matter that carries heavy metals. As the scenarios do not significantly differ in the degree to which the worst particulate emitters—small CHP stations and existing coal and lignite stations generally—continue to produce power, results are virtually identical across the cases.

5.3 Conclusion

An Elfin data set for Poland more refined than any previously available has been built and used to run four scenarios. Results show that natural gas is a highly desirable fuel for future power generation in Poland, but primarily as a peaking resource. As the current system is inflexible and peaking capacity appears to be the most pressing need, this result is not surprising, and this need for peaking resources is a robust result across diverse assumptions. However, including nuclear as a generation option shows natural gas to be less desirable than the PPGCo suggests, and, despite the PPGCo's claims to the contrary, nuclear power cannot be ruled out in Poland on economic grounds alone. In the unconstrained Elfin scenarios, using PPGCo assumptions, nuclear power is attractive, especially after 2010. However, the attractiveness of nuclear generation proves sensitive to certain input variables, notably fixed operating and maintenance cost, and possible carbon taxes. Further assessment of the viability of a Polish nuclear program would require considerable careful consideration of the uncertainty in some central assumptions, as well as careful review of other political, legal, and environmental problems associated with nuclear power. If the nuclear option is taken, the effectiveness of the DSM effect tested to lower environmental damage is limited because of the high load factor nature of the effect, which tends to displace nuclear generation rather than thermal.

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