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SELECTION FRAMEWORK FOR POWERPLANT CAPACITY MIX

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ABSTRACT

This paper illustrates multiattribute decision analysis in selecting powerplant capacity mix for the National Power Corporation that will meet the power demand of the Philippines by 2005. The objective of this study is to provide a framework for the decision making analysis of the Systems Planning Department of National Power Corporation. The preferences of two managers from the Systems Planning Department were elicited.

The preferences and value judgments of the two decision makers on specified levels of production cost (capital cost, operation and maintenance costs, thermal energy needed), fatalities, environmental degradation (radioactive waste, sulfur dioxide, air particulate, nitrogen dioxide and hydrogen sulfide releases), socio-political acceptability and land use were determined. There were ten (10) powerplant capacity mix alternatives generated.

The preference model of decision maker 1 is multiplicative while decision maker 2 is multiplicative with additive submodels. The alternatives that maximizes the use of combined cycle gas turbine and the use of fuel oil were ranked first and second, respectively, by the decision makers.

INTRODUCTION

The National Power Corporation (NPC), a government controlled corporation, seeks to fulfill its mission of providing reliable supply of electricity at reasonable cost within the framework of national socio-economic policies (16). The total installed capacity as of the end of 1994 is 9,061 MW comprising of 57.9% coming from the thermal powerplants using bunker oil and diesel, 24.9% from hydroelectric powerplants, 12.1% from geothermal powerplants and 5.1% from coal-fired powerplants as shown in Table 1 [14]. To meet the capacity demand of 17,514.1 MW in 2005 [14], a total capacity addition of 8,453.1 MW is needed.

The proposed powerplant capacity mix in 2005 is given in Table 1 [13,14]. The difference in the levels of total capacity needed for 2005 in the 1991 Power Development Program (PDP) from the 1994 PDP was due to the increase in the predicted residential, commercial and industrial sales based mainly from the 1991 gross regional domestic product. The recent discovery of natural gas in Palawan also changes the proposed powerplant capacity mix. Coal and geothermal based powerplant capacities were decreased. In the 1995 PDP, the private power participation has increased from 32% by the end of 1994 and expected to be 61% by 2005. The 1991 PDP only predicted 21.6% participation from private industries. Also the interconnection projects of NPC designed to share the reserved capacity of the Visayas (particularly geothermal resources) to Luzon and Mindanao will be implemented until 2005 as described in the 1995 PDP.

The currently used procedure in determining the powerplant capacity mix in NPC is economic in nature. The Energy and Power Evaluation Program of the Wein Automatic System Planning Software is used as the generation planning tool to derive the least-cost expansion program. Initially, candidate projects are screened through the production cost analysis. Candidate powerplants that are obviously uneconomical were discarded through the use of screening curves which chart the production cost of each alternative powerplant based on their different operating modes. Powerplants which are most likely to be near-optimal are included in the set of allowable configurations. All configurations generated are simulated probabilistically and the most economical option which meets the Loss-of-Load Probability (LOLP) of one day per year is selected. LOLP of one day is a reliability criterion that requires that the projected load will not exceed the capacity by more than 24 hours each year. In Mindanao, an additional reliability criterion of energy-not-served of 0.3 percent is included.

The Systems Planning Department of the Corporate Planning Group of NPC is in-charge of generating the ten year power development program which includes the powerplant capacity mix. The powerplant capacity mix is then submitted to the NPC Board for approval. Once approved, the siting and feasibility study of the identified powerplants are conducted by the Engineering Group. The site with the least engineering cost will be selected and endorsed to the NPC Board for approval. A feasibility study is then conducted for confirmation of initial findings.

This paper illustrates Multiattribute Decision Analysis (MDA) as the selection framework for powerplants capacity mix. The objective of this study is to provide a framework for decision making analysis of the Systems Planning Department of NPC in order to assist the decision makers in the formulation of an appropriate powerplant capacity mix and to elicit the preferences of the decision makers. The multiattribute decision analysis measures up much better in terms of quality analysis and perception than the other procedures because the complicating features of powerplant problems such as production cost, environmental impacts or social acceptability are explicitly addressed.

For example, the decision of whether to increase the capacity of Masinloc coal fired powerplant in Zambales or to construct the San Roque Dam in Benguet to supply the electricity demand of Luzon can be rationalized to identify and resolved conflicts of each type of powerplant. Coal-fired powerplant emits gaseous pollutants while the hydroelectric powerplant does not. However, hydroelectric powerplant causes land inundation but has low operating cost. MDA procedure allows the inclusion of uncertainties and value judgments. MDA can therefore reduce the likelihood of a poor outcome and provide a rationale and documentation for supporting the decision to management, regulators and the public. The analysis stimulate constructive discussion and provide framework for identifying and resolving conflicts.

Table 1. Summary of National Power Corporation Installed and Proposed Capacity [13,14]

GRID/PLANT TYPE	CAPACITY (MW)			
	1990 (a)	2000 (b)	2005 (b)	2005 (c)
PHILIPPINES	6,108	11,353	16,261	17,514.1
• Oil-Based	2,683	3,755	3,771	4,506.2
• Hydropower	2,132	2,485	3,520	3,552.9
• Geothermal	888	2,566	2,723	2,134
• Coal	405	2,505	6,205	4,621
• Natural Gas	0	42	42	2,700
LUZON	4,391	8,706	12,606	16,371.6 (d)
• Oil-Based	2,205	2,835	2,835	3,860.7
• Hydropower	1,226	1,494	1,794	2,722.9
• Geothermal	660	1,935	1,935	2,014
• Coal	300	2,400	6,000	3,791
• Natural Gas	0	42	42	2,700
• Noncon (e)				75
• Various (f)				1,208
VISAYAS	664	944	1,180	
• Oil-Based	329	441	457	
• Hydropower	2	7	7	
• Geothermal	228	391	511	
• Coal	105	105	205	
MINDANAO	1,053	1,703	2,355	2,846
• Oil-Based	149	479	479	646
• Hydropower	904	984	1,636	830
• Geothermal	0	240	240	120
• Coal	0	0	0	1,250

Notes:

(a) Installed capacity based on 1991 NPC Power Development Program
(b) Predicted capacity based on 1991 NPC Power Development Program
(c) Based on 1995 NPC Power Development Program
(d) Luzon and Visayas Grids share the same capacity due to Interconnection
(e) Noncon may consist of wind, solar, or tidal energy
(f) Various is the capacity contribution of Manila Electric Company

METHODOLOGY

Multiattribute Decision Analysis model has been discussed very extensively by Keeney and Raiffa (1976), Edwards and Newman (1982), and Von Winterfeldt and Edwards (1986). It is anchored on the likelihood of the possible consequences of each alternative and the decision maker's preferences for those possible consequences which are quantified and incorporated formally into the analysis of the selection problem. Tradeoffs between different social objectives are identified and quantified to aid policy makers in formulating decisions that achieve the best possible compromise between conflicting goals. Existing information, collected data, models and professional judgments are used to quantify the likelihood of various consequences. Utility theory is used to quantify preferences. Utility theory and measurements have been explained considerably by Fishburn (1970) and Krantz, et al. (1971). The methodology consists of identifying alternatives, specifying objectives and attributes, describing possible impacts, evaluating impacts, and analyzing and comparing alternatives. The MDA concepts have been liberally adapted and used from the above authors.

MDA has been applied by Goicoechea, et al. (1982) in engineering and business applications, and Stokey and Zeckhauser (1978) in policy analysis. Most importantly, Keeney (1980) applied it to siting energy facilities, and Keeney, Foell and Buehring (1976), and Foell, et al. (1981) for the Wisconsin set of energy/environment models for regional planning and management.

This study was particularly intended for the NPC President, being the chief executive officer, as the decision maker. However, the request was endorsed to its Systems Planning Department managers due to the unavailability of the President and the Vice-President for Planning Services. The Systems Planning Department is in-charge of generating the suitable powerplant capacity mix. Decision maker 1 (D_1) is Mr. Manolo C. Quintia, manager of Luzon Engineering Division. Mr. Quintia is 45 years old and a mechanical engineer. Decision Maker 2 (D_2) is Mr. Enrico G. Esguerra, the manager of the Systems Planning Department. Mr. Esguerra is an electrical engineer. Both have 10 to 15 years experience in powerplant operation and systems planning.

Identifying Alternatives

The total capacity requirements from 1991 to 2005 were calculated based on the probable growth rates in Luzon, Visayas, and Mindanao, using econometric, macro model, trending and simplistic approach [13]. The econometric method, in particular, makes use of the gross regional domestic product to forecast energy sales and power demand.

The powerplant capacity mix formulated were based on the projected energy demands of the Philippines from 1991 to 2005, the national government policies, and the 1991 PDP. The Philippines' hydropower, geothermal, natural gas, and coal resources, Build-Operate-Transfer/Build-Tranfer-Lease-Operate (BOT/BTLO) schemes being adopted by NPC, and the rehabilitation of old powerplants were part of the basis in the formulation of the different alternative options.

Specifying Objectives and Attributes

General concerns associated with different types of powerplants are identified from operating experiences of existing geothermal, hydroelectric, gas turbine, diesel-fired, and coal-fired powerplants. Attributes are established to indicate the degree to which objectives are achieved. For each of the attributes, a measurement scale was derived.

Attributes can either have natural scale or a constructed scale. For example, capital cost has a natural scale since it is quantitatively defined as a cost in terms of dollars while socio-political acceptability has a constructed scale. Natural and constructed scales measure either the direct attribute or the proxy attribute. A direct attribute measures the degree to which an objective is achieved. The proxy attribute has some relationship to the objective but may never be formalized and may not be precisely known. For example, sulfur dioxide releases intend to capture the undesirable impacts of pollution such as damage to properties and crops, odors, etc.

Describing Possible Impacts

The consequences associated with each alternative can be characterized by the levels by which the attributes assume. Data on power costs, environmental concerns, land use and socio-political acceptability were taken from the 1991 PDP, environmental impact assessments of NPC's proposed projects and other publications [3, 4, 5, 8, 13, 15, 19]. The possible impacts of each alternative were assessed by collecting and synthesizing data, modeling the process, and assessing professional judgments directly.

The assumptions used in the generation of the levels of attributes are an economic discount rate of 12 percent; a dollar exchange rate of 28 Philippine peso to the United States of America dollar (US$, 1991); plant factors of 85% for geothermal, 75% for coal-fired, 80% for combined cycle gas turbine, 75% for gas turbine, 59% for hydroelectric, 70% for natural gas-fired, 70% for nuclear and 75% for diesel-fired powerplants; crude oil prices at US$20 per barrel in 1991 with 3 percent annual escalation; imported coal at US$50 per metric ton in 1991 with annual escalation of 1%; and plant costs based on NPC Engineering Group estimates [13].

Evaluation of Impacts

The evaluation determines the relative desirability of the consequence $x = (x_1, x_2, \ldots, x_n)$ where x_1 is the specific amount of attribute X_1, and the utility function. The utility function $u(x_1, x_2, \ldots, x_n)$ over the attributes $X_1, X_2, \ldots, X_n$ assessed and $(X_1, X_2, \ldots, X_n)$ is preferred than $(X_1', X_2', \ldots, X_n')$ if $u(x_1, x_2, \ldots, x_n)$ is greater than $u(x_1', x_2', \ldots, x_n')$.

The assessment procedure includes familiarizing the decision makers with the concepts of utility theory, verifying preferential independence and utility independence assumptions; assessing single-attribute utility functions; evaluating the scaling constants; and checking for consistency and reiterating.

For the assumption of preferential independence, the pair of attributes (X_1, X_2) is preferentially independent of the other attributes $X_3, X_4, \ldots, X_n$ if the preference order for consequences involving only changes in the levels of X_1 and X_2 does not depend on the levels at which attributes X_3, X_4, ...,X_n are fixed [11]. This is equivalent to saying that the value tradeoffs between production cost and fatalities does not depend on environmental degradation, socio-political acceptability and land use.

For the assumption of utility independence, attribute X_1 is utility independent of attributes X_2, X_3, ..., X_n if the preference order for lotteries involving only changes in the level of X_1 does not depend on the levels at which attributes X_2, X_3, ..., X_n are fixed. A lottery is defined by specifying a mutually exclusive and collectively exhaustive set of possible consequences and probabilities associated with the occurrence of each [11]. This is equivalent to saying that decisions concerning alternatives can be made by considering the overall impacts on fatalities only regardless of the levels of production cost, environmental degradation, socio-political acceptability and land use.

The structure of the utility function $u(\vec{x})$ is either an additive where

$$u(\vec{x}) = \sum_{i=1}^{n} k_i u(x_i)$$

and

$$\sum_{i=1}^{n} k_i = 1$$

or multiplicative where

$$u(\vec{x}) = \frac{1}{k}\left[\prod_{i=1}^{n}\left(1 + kk_i u_i(x_i)\right) - 1\right]$$

where u and u_i are utility functions scaled from zero to one and k_i are scaling constants with $0 < k_i < 1$, and $k > -1$.

The actual assessment process requires personal interaction with the decision makers, since their utility functions are formalization of their subjective preferences. The total assessment process required five (5) meetings which lasted for at least two (2) hours per session with the decision makers individually. The concepts of MDA were presented to the decision makers during the first session.

Analyzing and Comparing Alternatives

The expected utility, Eu_j is the summation (or integration) of the probability of each possible consequence, s_j multiplied by the utility of that consequence which is the formal way of combining the chances of and preferences for consequences. The expected utility for each alternative, A_j is:

$$Eu_j = \int s_j(x)u(x)dx$$

The higher the expected utility, the more desirable is the alternative. The magnitude of the Eu_j establishes a ranking that reflects the decision maker's preferences for one set of consequences over other sets. The evaluation of the alternatives derived from this method reflects the degree of achievement of the objectives.

RESULTS AND ANALYSIS

The ten (10) powerplant capacity mix alternatives formulated are given in Table 2. Alternative 1 is NPC's proposed capacity mix for the year 2005 with the rehabilitation of a 55 MW coal-fired and 552.5 MW diesel-fired powerplants [13]. The total capacity proposed under BOT/BTLO schemes is 3,242 MW. Alternative 2 is the proposed coal-fired powerplants (4800 MW) for Luzon to be substituted by natural gas-fired powerplants, and the maximum use of indigenous resources. Alternative 3 maximizes the use of geothermal resources and no coal-fired powerplants shall be installed from year 1995 to 2005. Alternative 4 maximizes the use of coal. Alternative 5 is the conversion of the proposed coal-fired and geothermal powerplants for Mindanao and Luzon from year 1995 to 2005 to combined cycle (gas turbine with reheat cycle) powerplants. Alternative 6 uses nuclear power and converts the proposed geothermal powerplants in Mindanao to hydroelectric powerplants. Alternative 7 increases use of fuel oil and converts the proposed coal-fired powerplants and geothermal powerplants in Mindanao to gas turbine powerplants. Alternative 8 maximizes the use of hydropower resources. Alternative 9 places 80% of the proposed capacity of NPC under BOT/BTLO schemes. Alternative 10 is the same as Alternative 1 but the 55 MW coal-fired powerplants and 552.5 MW diesel fired-powerplants proposed for rehabilitation shall be substituted by combined cycle. For alternative 2 to 8 rehabilitation of the 55 MW coal-fired powerplants and 552.5 MW diesel-fired powerplants shall be undertaken as in Alternative 1, and the BOT/BTLO schemes shall not be adopted.

The objectives are to minimize production cost, minimize fatalities, minimize environmental degradation, maximize socio-political acceptability and minimize land use. Production cost, X_1, in util, refers to the combined effect of capital cost, operation and maintenance costs, and thermal energy needed. Capital cost is the total cost, $X_{1.1}$ of building the powerplants in US dollars. Operation and maintenance cost $X_{1.2}$ is the total cost of maintaining and operating the powerplant in US$/year. Thermal energy needed, $X_{1.3}$ is the energy used to generate power. It pertains to energy from coal, geothermal fluid, oil and nuclear fuel to generate power in kWh per year. Fatalities, X_2, are the number of deaths due to mining of fossil fuels, accidents, radioactive exposure, etc.

Environmental degradation, X_3, in util, composed of radioactive waste releases, sulfur dioxide releases, air particulate releases, nitrogen dioxide releases and hydrogen sulfide releases. Radioactive waste releases, $X_{3.1}$ indicate implications resulting from the waste itself such as genetic impacts, etc. in Curies per year. Sulfur dioxide (SO_2) releases, $X_{3.2}$, in tons per year, air

Table 2. Energy Policy and Proposed Capacity Mix

ALTER-NATIVE	DESCRIPTION OF ENERGY POLICY OPTION	TOTAL PROPOSED CAPACITY MIX FOR 2005 [Proposed Capacity for BOT/BTLO Schemes] (in MW)			
1	• NPC's proposed capacity mix for the year 2005 with rehabilitation of a 55 MW coal-fired and 552.5 MW diesel-fired powerplants as per 1991 Power Development Program.	Coal-fired: Combined Cycle: Diesel-fired: Gas Turbine:	6,105 [1,880] 510 [510] 2,482 779 [200]	Geothermal: Hydroelectric: Natural Gas:	2,723 [852] 3,520 42 [42]
2	• The proposed coal-fired powerplant capacity (4800 MW) for Luzon shall be substituted by natural gas-fired powerplants. Maximum use of indigenous resources from 1995 to 2005.	Coal-fired: Combined Cycle: Diesel-fired: Gas Turbine:	1,305 510 2,482 779	Geothermal: Hydroelectric: Natural Gas:	2,723 3,520 4,842
3	• Use of geothermal resources will be maximized. No coal-fired powerplants shall be installed from year 1995-2005.	Coal-fired: Combined Cycle: Diesel-fired: Gas Turbine:	1,305 510 2,482 779	Geothermal: Hydroelectric: Natural Gas:	3,701 7,803 995
4	• Use of coal is maximized.	Coal-fired: Combined Cycle: Diesel-fired: Gas Turbine:	8,304 510 2,482 779	Geothermal: Hydroelectric: Natural Gas:	1,303 2,300 42
5	• The proposed coal-fired and geothermal powerplants for Mindanao and Luzon from 1995 to 2005 shall be converted to combined cycle (gas turbine with reheat cycle) powerplants.	Coal-fired: Combined Cycle: Diesel-fired: Gas Turbine:	1,305 6,170 2,482 779	Geothermal: Hydroelectric: Natural Gas:	1,543 3,520 42
6	• The proposed geothermal and coal-fired powerplants for Luzon shall be converted to nuclear power and the proposed geothermal powerplants in Mindanao shall be converted to hydroelectric powerplants.	Coal-fired: Combined Cycle: Diesel-fired: Gas Turbine:	1,305 510 2,482 779	Geothermal: Hydroelectric: Natural Gas: Nuclear Power:	1,503 3,982 42 5,858
7	• Increase use of fuel oil. Convert proposed coal-fired powerplants in Luzon and geothermal powerplants in Mindanao to gas turbine powerplants.	Coal-fired: Combined Cycle: Diesel-fired: Gas Turbine:	1,305 510 4,966 3,477	Geothermal: Hydroelectric: Natural Gas:	2,523 2,488 42
8	• Use of hydropower resources shall be maximized.	Coal-fired: Combined Cycle: Diesel-fired: Gas Turbine:	4,161 510 2,511 2,878	Geothermal: Hydroelectric: Natural Gas:	2,283 7,800 42

9	80% of the proposed capacity by NPC from 1991 to 2005 shall be under BOT/BTLO schemes.	Coal-fired: 6,105 [5,700] Combined Cycle: 510 [510] Diesel-fired: 2,482 [72] Gas Turbine: 779 [468] Geothermal: 2,723 [900] Hydroelectric: 3,520 [200] Natural Gas: 42 [42]
10	• Same as Alternative 1 but the 55 MW coal-fired and the 552.5 MW diesel-fired powerplants proposed for rehabilitation shall be substituted by combined cycle.	Coal-fired: 6,105 [1,880] Combined Cycle: 1,161 [1,161] Diesel-fired: 2,482 [72] Gas Turbine: 778 [200] Geothermal: 2,723 [852] Hydroelectric: 3,520 Natural Gas: 42 [42]

Note:

In Alternatives 2 to 8 rehabilitation of the 55 MW coal-fired and 552.5 MW diesel-fired powerplants shall be undertaken as in Alternative 1, and the BOT/BTLO schemes shall not be adopted.

particulate releases, $X_{3.3}$, in tons per year, Nitrogen dioxide (NO_2) releases, $X_{3.4}$, in tons per year, and Hydrogen sulfide (H_2S) releases, $X_{3.5}$, in tons per year are intended to capture all the undesirable impacts of pollution other than health impacts. This may include damage to properties and crops, odors, etc.

Social and political acceptability, X_4, shall be measured by the level of acceptance of the project by the public, local and national governments, and non-government organizations. This attribute is represented on constructed scale defined as: (1) The project is very acceptable to the public, local and national governments and non-governmental organizations; (2) People directly affected is against the project. Some non-governmental organizations are against the project. Local and national governments are supportive of the project; (3) The project is not acceptable to the people leaving near the proposed plant site. Some non-governmental organizations are against the project. Local and national governments approved the project; (4) The project is not acceptable to most members of the community and non-governmental organizations are against the project. Local government has some doubts on the project. National government is in favor of the project; and (5) The project is not acceptable to the public, local and national governments and non-governmental organizations.

Land use, X_5, is the space of land required for the plant in square meters. This include areas for mining, waste disposal, land use at plant and fuel cycle facilities, reservation, watershed, etc. The objective hierarchy is shown in Figure 1.

The specific values of attributes for each alternative are given in Table 3. Alternative 8 which maximizes the use of hydropower has the highest capital cost while Alternative 9 which utilizes the BOT/BTLO schemes gave the lowest capital cost. Operation and maintenance costs considerably increase in alternatives implementing the BOT/BTLO schemes because of the annual energy charged to NPC by private contractors. The capacity mix requiring the lowest thermal energy is Alternative 7 which uses fuel oil. Fuel oil has higher heating value compared to coal.

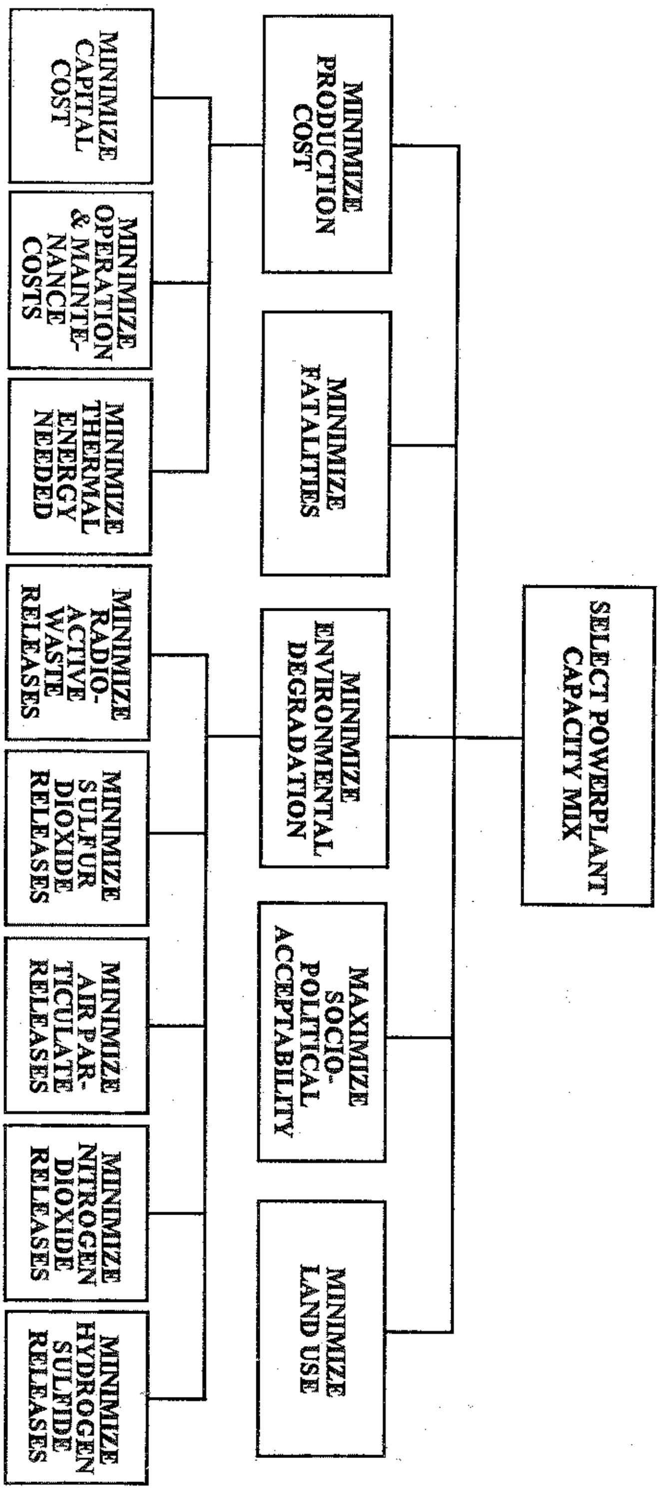


Figure 1. Objectives Hierarchy for Evaluating the Powerplant Capacity Mix

Table 3. Alternative Profile of Various Powerplant Capacity Mix

ATTRIBUTE	ALTERNATIVE									
	1	2	3	4	5	6	7	8	9	10
Production Cost, X_1, util										
• Capital Cost, $X_{1.1}$, $10^9\ \$$	11.4	11.7	16.6	15.8	11.2	16.3	11.2	20.4	4.2	11.2
• Operation and Maintenance Costs, $X_{1.2}$, $10^9\ \$/yr$	1.4	0.2	0.2	0.3	0.2	0.3	0.2	0.2	2.7	1.7
• Thermal Energy Needed, $X_{1.3}$, 10^9 kWh/yr	329	328	310	293	268	282	267	269	329	340
Fatalities, X_2, death	6,210	1,821	1,610	8,343	1,859	4,858	1,825	4,329	6,210	6,248
Environmental Degradation, X_3, util										
• Radioactive Waste Releases, $X_{3.1}$, Ci	394	84	84	535	84	822 E+6	84	268	394	394
• Sulfur Dioxide Releases, $X_{3.2}$, 10^3 ton/yr	275	144	102	359	153	92	148	201	275	282
• Air Particulate Releases, $X_{3.3}$, 10^3 ton/yr	74.3	20.3	18.1	100.3	20.8	17.6	20.6	51.4	74.3	74.7
• Nitrogen Dioxide Releases, $X_{3.4}$, 10^3 ton/yr	118	249	139	121	89	111	260	116	118	136
• Hydrogen Sulfide Releases, $X_{3.5}$, 10^3 ton/yr	24.5	24.5	58.2	11.7	13.9	13.5	22.7	20.5	24.5	24.5
Socio-Political Acceptability, X_4, Scale	4	3	3	4	1	5	3	2	4	4
Land use, X_5, 10^7 m^2	632	589	866	428	437	415	523	547	632	637

The very high capacity of coal usage in Alternative 4 causes the highest number of deaths. Probable fatalities due to coal usage is less than when using nuclear power (Alternative 6). However, the capacity allotted for nuclear energy in Alternative 6 is only 5,850 MW compared to coal in Alternative 4 of 8,304 MW.

In environmental concerns, each type of powerplant has its own distinct type of pollutant releases. Alternative 4 with high coal usage have the highest sulfur dioxide and air particulate releases. Gas turbine and diesel-fired powerplants (Alternative 7) which have higher combustion temperature, releases the highest level of nitrogen dioxide. Since only geothermal sources emit hydrogen sulfide. Alternative 3 has the highest value. Radioactive waste is always associated with nuclear power (Alternative 6).

Socio-political acceptability is high for oil-fired plants like gas turbines as compared to coal and geothermal because of its conspicuous environmental impacts. The proposed capacity mix of NPC (Alternative 1) requires the most extensive use of land while Alternative 6 requires the least.

The subjective preferences of the decision makers were formalized in terms of utility functions. The assessment of the utility functions was done using the basic reference lottery ticket technique. Questionnaire and graphical representation were also employed. For example, by considering preferences between a series of specified levels of capital cost and a 50-50 chance lottery yielding either a $20.4B or a $4.2B capital cost, it was decided by Decision Maker 1 that he would be indifferent to a specified level of $10B. Since utility is a measure of preference, the 50-50 chance lottery and $10B have equal expected utilities. D_1 is indifferent at a 25-75 chance lottery and $15B and he was indifferent at a 75-25 chance lottery and $6B as shown in Figure 2. The utility functions of the other attributes for D_1 are constructed in Figure 3 to 12. The same process was applied to Decision Maker 2 to derive his utility functions which are superimposed in Figures 2 to 12.

In fatalities, D_1 becomes risk prone only at high fatalities but becomes risk averse as deaths become less than 5,000. D_2 is risk prone at all levels of fatalities (Figure 5). With radioactive waste releases, both decision makers are extremely risk prone. Both decision makers become risk averse on socio-political acceptability with D_1 more risk averse than D_2 (Figure 11).

The scaling constants, k_i were assessed by ranking the attributes according to importance and then quantifying the magnitude of each k_i. The ranking of the main model and the nested submodels for production cost and environmental degradation are as follows:

Main Model
D_1: $k_1 > k_2 > k_5 > k_3 > k_4$
D_2: $k_1 > k_2 > k_3 > k_4 > k_5$

Production Cost Submodel
D_1: $k_{1.1} > k_{1.2} > k_{1.3}$
D_2: $k_{1.1} \approx k_{1.2} \approx k_{1.3}$

Environmental Degradation Submodel
D_1: $k_{3.1} > k_{3.3} > k_{3.2} > k_{3.5} > k_{3.4}$
D_2: $k_{3.1} > k_{3.2} > k_{3.3} > k_{3.4} > k_{3.5}$

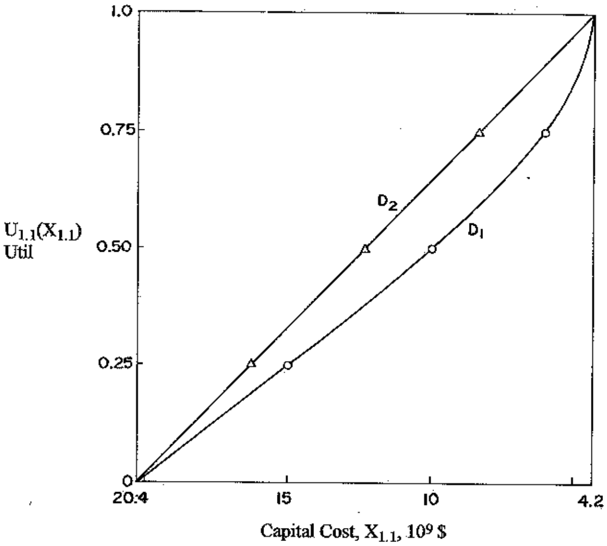


Figure 2. Utility Function of Capital Cost

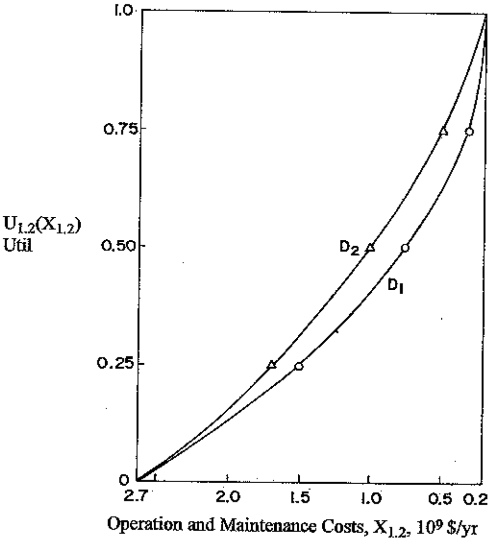


Figure 3. Utility Function of Operation and Maintenance Costs

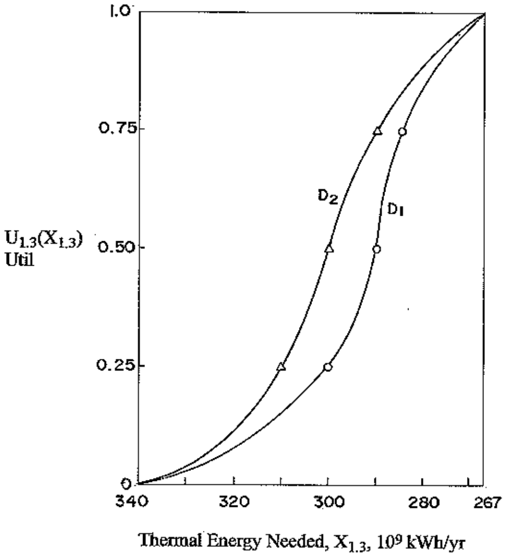


Figure 4. Utility Function of Thermal Energy Needed

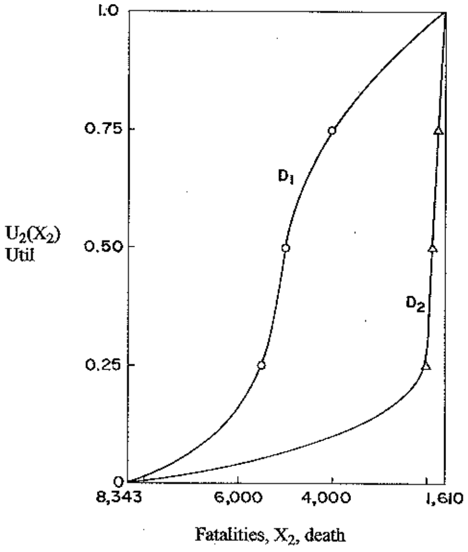


Figure 5. Utility Function of Fatalities

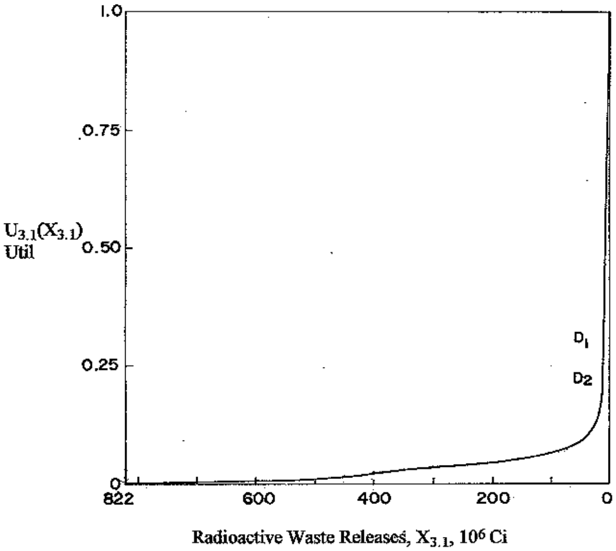


Figure 6. Utility Function of Radioactive Waste Releases

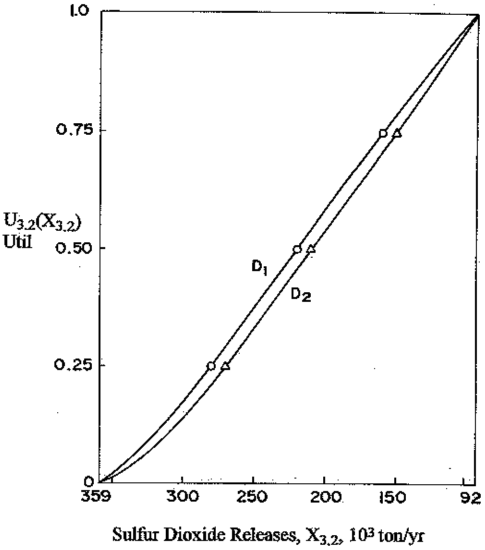


Figure 7. Utility Function of Sulfur Dioxide Releases

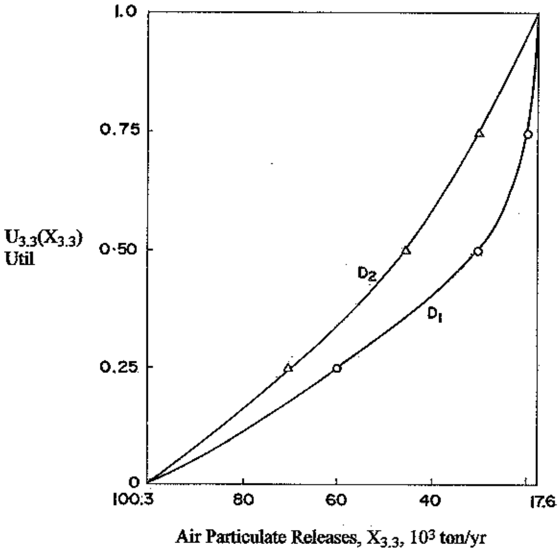


Figure 8. Utility Function of Air Particulate Releases

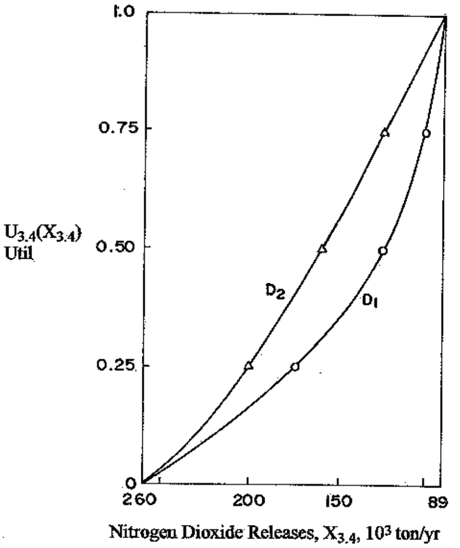


Figure 9. Utility Function of Nitrogen Dioxide Releases

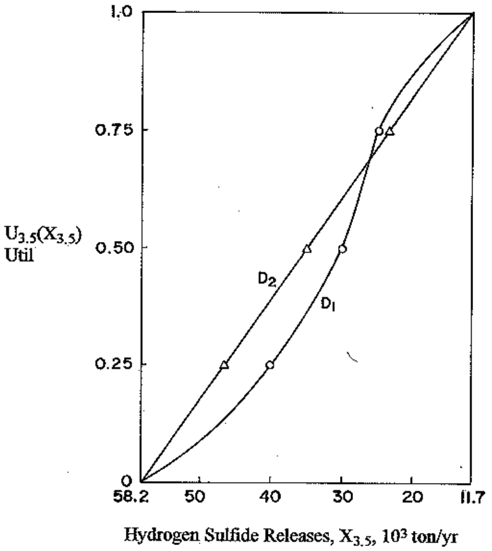


Figure 10. Utility Function of Hydrogen Sulfide Releases

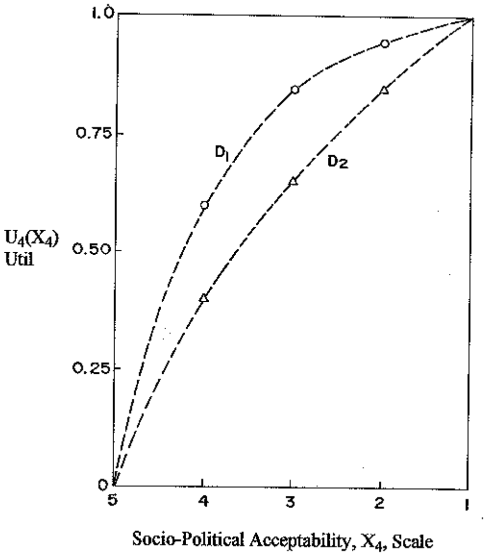


Figure 11. Utility Function of Socio-Political Acceptability

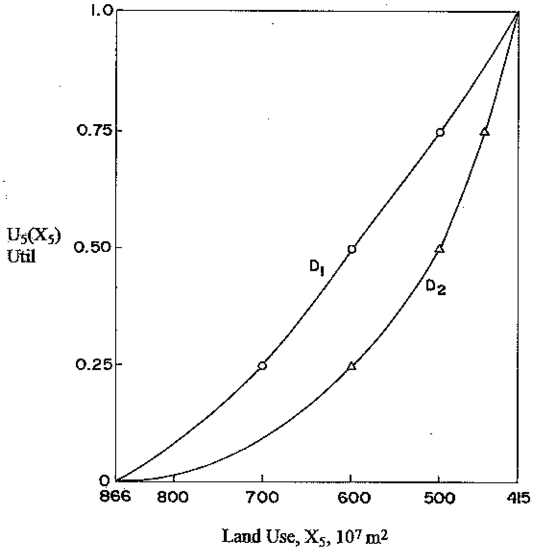


Figure 12. Utility Function of Land Use

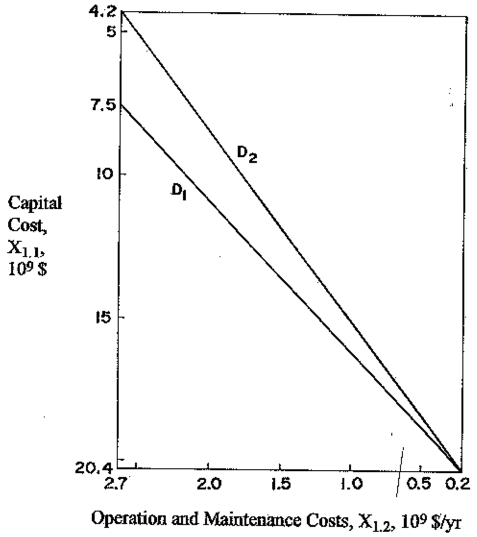


Figure 13. Tradeoffs Between Capital Cost and Operation and Maintenance Costs

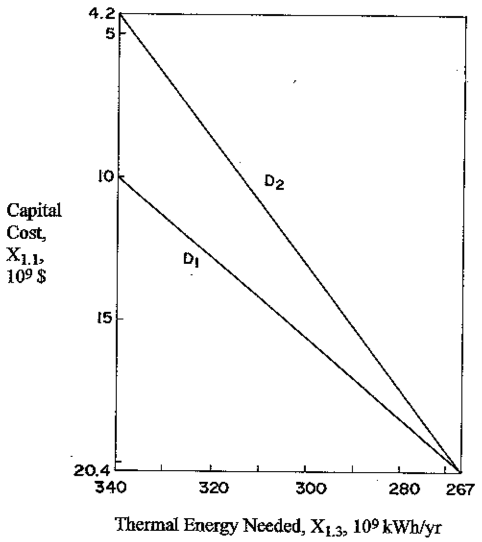
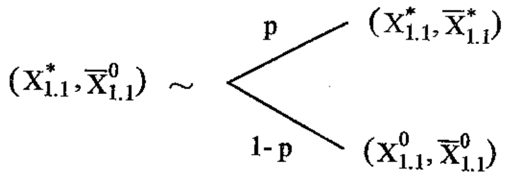


Figure 14. Tradeoffs Between Capital Cost and Thermal Energy Needed



$D_1: \; p_1 = 0.75$

$D_2: \; p_2 = \frac{1}{3}$

Figure 15. Assessment of Indifference Probability for Capital Cost

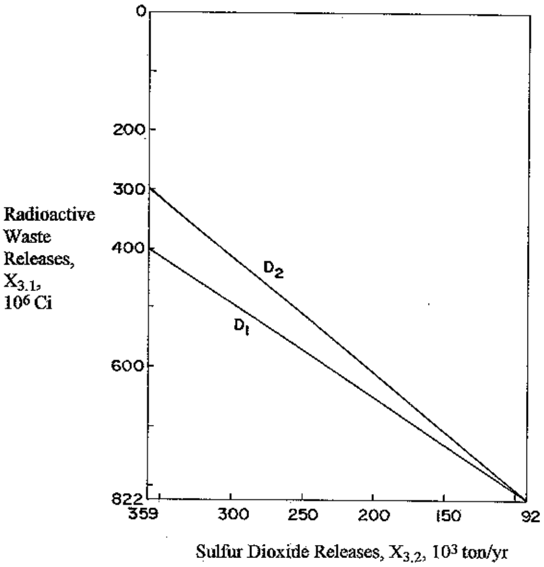


Figure 16. Tradeoffs Between Radioactive Waste Releases and Sulfur Dioxide Releases

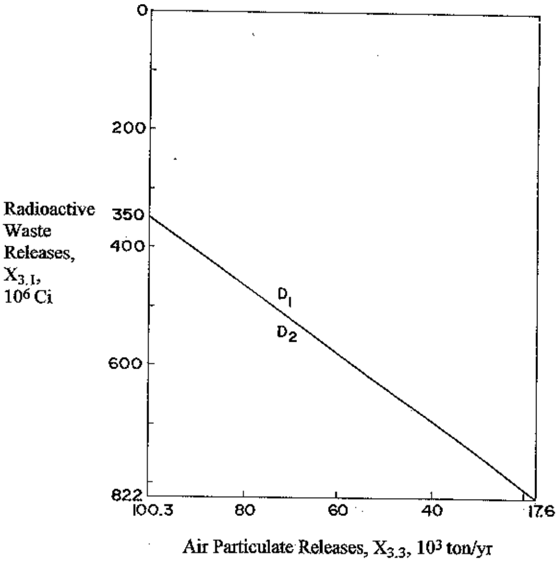


Figure 17. Tradeoffs Between Radioactive Waste Releases and Air Particulate Releases

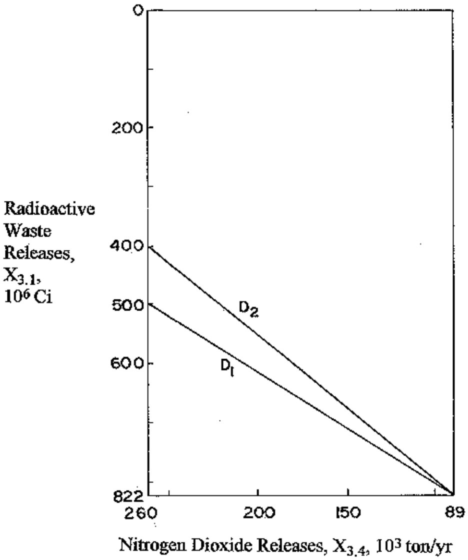


Figure 18. Tradeoffs Between Radioactive Waste Releases and Nitrogen Dioxide Releases

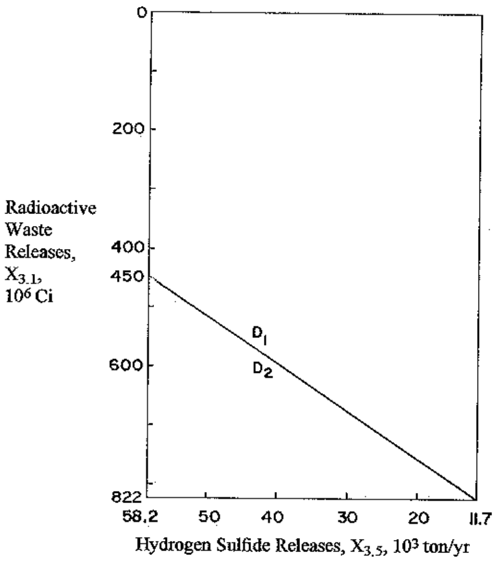
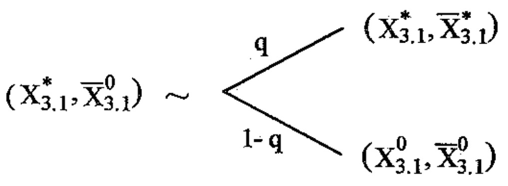


Figure 19. Tradeoffs Between Radioactive Waste Releases and Hydrogen Sulfide Releases



$D_1 : \; q_1 = 0.85$

$D_2 : \; q_2 = 0.9$

Figure 20. Assessment of Indifference Probability for Radioactive Waste Releases

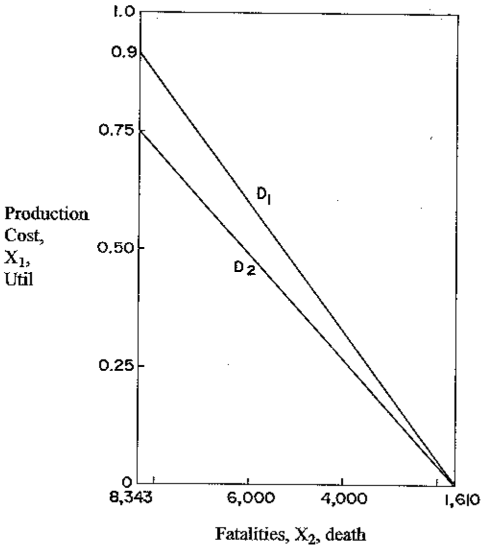


Figure 21. Tradeoffs Between Production Cost and Fatalities

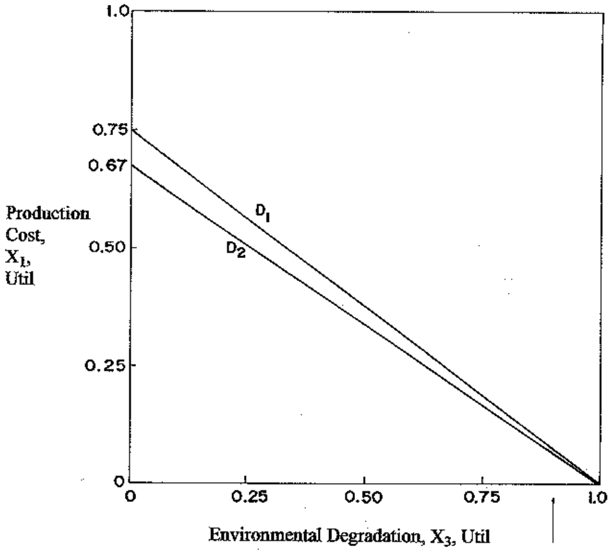


Figure 22. Tradeoffs Between Production Cost and Environmental Degradation

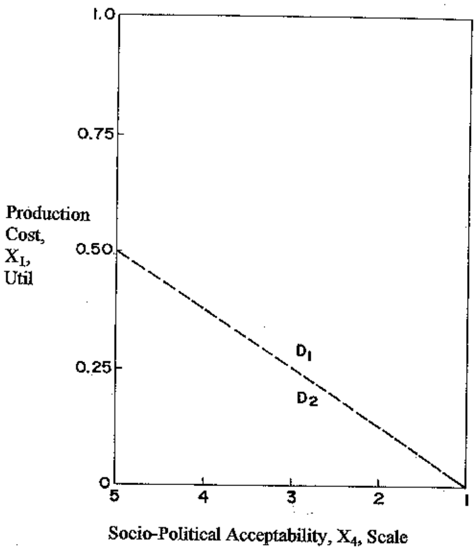


Figure 23. Tradeoffs Between Production Cost and Socio-Political Acceptability

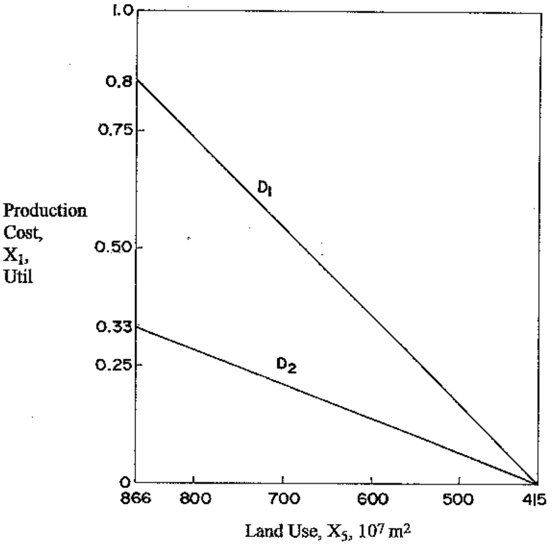
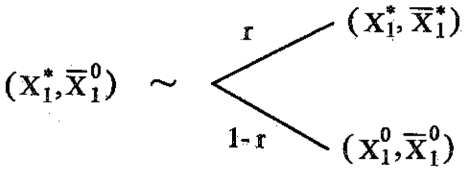


Figure 24. Tradeoffs Between Production Cost and Land Use



D_1: $r_1 = 0.8$

D_2: $r_2 = 0.75$

Figure 25. Assessment of Indifference Probability for Production Cost

The scaling constants indicate the relative importance of each attribute of specified ranges to the decision makers. In the main model, D_1 and D_2 rank production cost and then fatalities as the more important attributes. In the production cost submodel, D_2 decided that the capital cost, operation and maintenance costs, and thermal energy needed were equally important. In the environmental degradation submodel, both agreed that radioactive waste releases is the most important among other concerns.

The actual values of the scaling constants were calculated by assessing value tradeoffs between attributes and assessing the indifference probabilities. Value tradeoffs between attributes considers how much one is willing to give up on one attribute to gain a specific amount on another attribute. The value tradeoffs assessed for the production cost submodel is shown in Figures 13 and 14, for the environmental degradation submodel in Figures 16 to 19 and for the main model in Figures 21 to 24.

The assessment of indifference probability for capital cost is shown in Figure 15, radioactive waste releases in Figure 20 and production cost in Figure 25. In assessing the indifference probability for production cost for example, D_1 was asked to determine the probability (p_1) of having the best of all attributes or the probability ($1 - p_1$) of having all the worst attributes that is equally desirable for having for sure the best level of production cost and the worst levels for all the other attributes. His answer was $p_1 = 0.8$ (Figure 15).

The sum of the scaling constants for D_1 is found to be 3.16 for the main model which shows a multiplicative utility model. Solving for the value of k, resulted to $k = -0.995$. The nested submodels for attributes 1 and 3 resulted in the sum of scaling constants equal to 1.613 and 0.91, respectively. This implies that the nested submodels are multiplicative with k values for attributes 1 and 3 equal to -0.861 and 1.333, respectively. The preference model of D_1 is:

$$u(\vec{x}) = \frac{1}{k}\left[\prod_{i=1}^{5}\left(1 + kk_i u_i(x)\right) - 1\right]$$

where

$k_1 = 0.8 \quad k_2 = 0.72 \quad k_3 = 0.6 \quad k_4 = 0.4 \quad k_5 = 0.64 \quad k = -0.995$

$$u_1(x_1) = \frac{1}{k_A}\left[\prod_{m=1}^{3}\left(1 + k_A k_{1.m} u_{1.m}(x_{1.m})\right) - 1\right]$$

$k_{1.1} = 0.75 \quad k_{1.2} = 0.488 \quad k_{1.3} = 0.375 \quad k_A = -0.861$

$$u_3(x_3) = \frac{1}{k_B}\left[\prod_{n=1}^{5}\left(1 + k_B k_{3.n} u_{3.n}(x_{3.n})\right) - 1\right]$$

$k_{3.1} = 0.85 \quad k_{3.2} = 0.021 \quad k_{3.3} = 0.026 \quad k_{3.4} = -0.009$
$k_{3.5} = 0.013 \quad k_B = 1.333$

D_2 has an overall multiplicative utility model with $k = -0.969$. The nested submodels for production cost and environmental degradation are additive. The preference model of D_2 is:

$$u(\vec{x}) = \left[\prod_{i=1}^{5} \left(1 + kk_i u_i(x_i)\right) - 1 \right]$$

where

$k_1 = 0.75 \quad k_2 = 0.563 \quad k_3 = 0.503 \quad k_4 = 0.375 \quad k_5 = 0.248 \quad k = -0.969$

$$u_1(x_1) = \sum_{m=1}^{3} k_{1.m} u_{1.m}(x_{1.m})$$

$k_{1.1} = 0.333 \quad k_{1.2} = 0.333 \quad k_{1.3} = 0.333$

$$u_3(x_3) = \sum_{n=1}^{5} k_{3.n} u_{3.n}(x_{3.n})$$

$k_{3.1} = 0.9 \quad k_{3.2} = 0.036 \quad k_{3.3} = 0.027 \quad k_{3.4} = -0.023 \quad k_{3.5} = 0.014$

The ranking of the alternatives is shown in Figure 26. It is based on the derived expected utilities of D_1 and D_2 as entered in Table 4. Results indicate that both decision makers prefer Alternative 5 and 7 as the first and second powerplant capacity mix options, respectively. Alternative 5 increases the use of combined cycle in 1995 to 2005 in Luzon and Mindanao instead of using coal and geothermal while Alternative 7 proposes the use of fuel oil.

The decision makers indicated strong preferences for production cost and fatalities which resulted to having higher expected utilities for Alternatives 5, 7, 2, 3 and 8. These five alternatives cancel the inclusion of coal-fired powerplants in the capacity mix from year 1995 to 2005. The proposed capacity mix of NPC ranks 9 for D_1 and 8 for D_2. The policy option for nuclear powerplant gets the lowest rank from the two decision makers. When consulted, the decision makers agreed with the results of the model.

Individual preferences of the two decision makers were asked before the assessment process. D_1 indicated that he preferred the hydroelectric powerplant while D_2 preferred the capacity mix with BOT/BTLO schemes. Maximum use of hydropower resources (Alternative 8) ranked 4 for D_1 which is consistent because of its high expected utility value. What pulled down Alternative 8 to rank 4 is its high capital cost which has the highest preference for D_1.

BOT/BTLO schemes (Alternative 9) ranked 7 for D_2. Alternative 9 has the lowest capital cost and the highest operation and maintenance costs among the alternatives. For D_2 both attributes at their specified levels are equally important. The high fatalities and low rating for environmental degradation lowered the expected utility of Alternative 9.

CONCLUSIONS AND RECOMMENDATIONS

The constructed preference models can assist in evaluating powerplant capacity mix policies. The process substantially aid in identifying and sensitizing the decision makers of the Systems Planning Department on important issues like capital cost, operation and maintenance costs, thermal energy needed, fatalities, radioactive waste releases, sulfur dioxide releases, nitrogen oxides releases, air particulate releases, hydrogen sulfide releases, socio-political acceptability, and land use. The process also helped in generating and evaluating alternatives, isolating and resolving conflicts of judgment and preference among members of the decision making team and in this particular application, in identifying improvements. The decisions obtained however, reflect the preferences and value judgments of Mr. Quintia and Mr. Esguerra, and do not necessarily reflect the preference of NPC on powerplant capacity mix.

Using multiattribute decision analysis, preference models have been described for decision makers at the NPC Systems Planning Department. The preference model of Mr. Manolo Quintia is a multiplicative model. Mr. Enrico Esguerra has a multiplicative model with additive submodels.

The preferences of Mr. Quintia (in the order of highest preference) are production cost, fatalities, land use, environmental degradation, and socio-political acceptability. In production cost submodel, Mr. Quintia prefers capital cost, over operation and maintenance costs, and over thermal energy needed. In environmental degradation, radioactive waste releases is preferred over sulfur dioxide, nitrogen dioxide, air particulate and hydrogen sulfide releases.

Mr. Esguerra's preferences (in the order of highest preference) are production cost, fatalities, environmental degradation, socio-political acceptability and land use. In the production cost submodel, Mr. Esguerra has the same preferences for capital cost, operation and maintenance costs, and thermal energy needed. In environmental degradation, radioactive waste is highly preferred than the other pollutants.

Alternatives 5 and 7 are the first two capacity mix options most preferred by Mr. Quintia and Mr. Esguerra. The two alternatives feature the high share of combined cycle gas turbine and gas turbine powerplants which uses bunker and diesel oil. Additional coal and geothermal use in Luzon are not included from 1995 to 2005 in Alternatives 5 and 7. Alternatives 1,4, 9 and 10 which have high coal share in the capacity mix ranks low due to high preference of the decision makers on fatalities and environmental degradation. A policy involving implementation of a BOT/BTLO schemes that does not include coal-fired powerplants should be included in the alternatives in order for the BOT/BTLO schemes to have a higher rank for D_2.

Capacity mix utilizing high percentage of capital cost-intensive hydroelectric powerplants and geothermal powerplants lowers its desirability. Geothermal may be mixed with combined cycle gas turbines to lower down capital cost and land use.

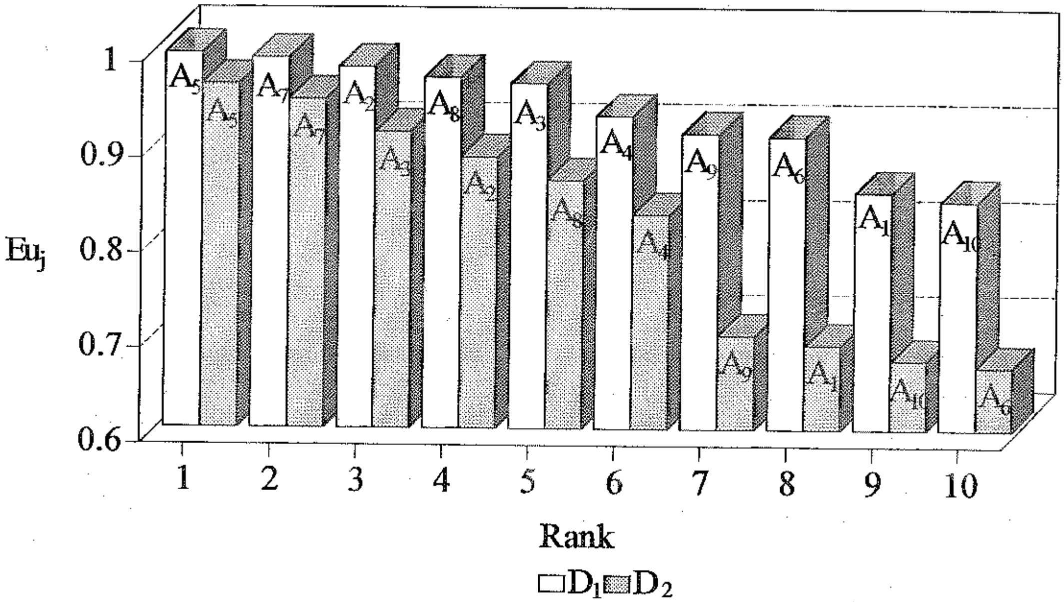


Figure 26. Ranking of the Alternatives

Table 4. Expected Utility

Alternative	Decision Maker 1	Decision Maker 2
	Expected Utility	Expected Utility
1	0.849	0.688
2	0.979	0.885
3	0.962	0.911
4	0.928	0.825
5	0.994	0.961
6	0.907	0.665
7	0.989	0.945
8	0.968	0.861
9	0.910	0.698
10	0.840	0.672

Coal-fired powerplants cause high fatalities and high environmental impacts which renders it unwise to pair with geothermal powerplants. Coal also requires high capital cost, high thermal energy needed and moderately low socio-political acceptability. It is apparent that the percentage of using coal must be minimized in any proposed capacity mix.

From 1990 to 1994, NPC has increased its capacity from 6,031 MW to 9,061 MW with oil thermal powerplant increasing from 43% to 57.9% [14]. This is parallel to the above decisions of Mr. Quintia and Mr. Esguerra which prefer a high share of combined cycle gas turbine and gas turbine powerplants using bunker oil. Their preference models were assessed in 1991.

It is recommended that fine tuning be done on the models to include group decision analysis. Sensitivity analysis should be simulated exhaustively. Other alternatives that include BOO (build-operate-own), ROM (rehabilitate-operate-maintain), and ROL (rehabilitate-operate-lease) and independent power producers (IPP) selling directly to consumers without NPC's intervention should be formulated.

It is further recommended that the methodology described in this report may be used to conduct formal assessments of the NPC's Board Members to aid them in structuring their general concerns in the selection of appropriate energy policy. The corporate specialist and systems planning analyst of NPC may want to consider MDA as a planning tool to select an appropriate capacity mix option. The model can be tried on public interest groups for the purpose of clarifying and understanding their positions on different general concerns such as the energy/environment issues.

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