Multiobjective Optimization for Electric Power Development in Indonesia

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INTISARI.

Tujuan studi ini adalah mengembangkan suatu model matematika untuk analisis perencanaan jangka panjang tenaga listrik di Indonesia dalam kerangka kebijaksanaan energi Nasional. Meskipun Indonesia merupakan negara penghasil minyak yang cukup besar, namun sebagian besar komoditi ini dialokasikan untuk ekspor. Kemudian untuk konsumsi dalam negeri pemerintah Indonesia melaksanakan kebijaksanaan diversifikasi. Mengingat cadangannya yang cukup besar, maka salah satu sumber daya energi primer yang perlu mendapat perhatian adalah batubara.

Pengembangan sistem pembangkit tenaga listrik dalam konteks tersebut akan menimbulkan kesukaran-kesukaran baru bagi para perencana dan pengambil keputusan, mengingat keterkaitannya dengan persoalan alokasi sumber daya yang kompleks dan permasalahan dampak lingkungan pemanfaatan batubara yang dinilai cukup besar.

Dalam studi ini telah dikembangkan suatu metodologi optimisasi multiobjektif dengan memilih tiga fungsi tujuan yang saling bertentangan yaitu :

o $f1$ = meminimumkan biaya total; o $f2$ = memaksimumkan penggunaan batubara; o $f3$ = meminimumkan dampak lingkungan.

Dalam model ini juga diperkenalkan konsep faktor penalti — γ sebagai kriteria untuk mencari solusi optimum. Faktor penalti — γ ditentukan berdasarkan azas perimbalan (trade-off) yang mampu menggambarkan seberapa jauh pengorbanan biaya total (Δ $f1$) harus diberikan untuk memperoleh imbalan penambahan penggunaan batubara Δ $f2$).

Solusi linear programming tujuan ganda, dinyatakan melalui penggambaran kurva trade-off antara kedua fungsi tujuan tersebut ($f1$ terhadap $f2$), dengan fungsi tujuan ketiga ($f3$) diperlakukan sebagai kendala yang terbagi menjadi tiga rentangan yaitu: dampak lingkungan rendah (L), menengah (M) dan tinggi (H).

Permintaan listrik untuk masing-masing sektor: industri ringan, industri berat dan rumah tangga & komersial, bersama dengan kaitan pola perubahan strukturnya dengan faktor beban sistem (load factor) diperoleh dengan melakukan analisis regresi kecenderungan variable ekonomi dan konsumsi tenaga listrik masa lalu.

Model Supply-demand kemudian diterapkan untuk analisis persoalan nyata perencanaan jangka panjang tenaga listrik di Indonesia (Repelita V, VI, VII dan VIII).

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INTRODUCTION.

Indonesia has large conventional energy resources in the form of oil, natural gas, coal and geothermal. However the availability of indigenous oil has resulted in a petroleum-dependent energy sector.

The heavy dependency in oil is also reflected in power sector: 81% of electricity production in 1984 are generated from oil fueled power plants.

Diversification policy launched by government of Indonesia (GOI) to reduce dependency on oil, will incline to push coal as the most significant primary energy resources for large scale electric power geration. If expectation to maximese the use of coal will be realized in future, how do we cope with the problem of investment and the problem of environment. At the same time its exploitation rate and the availability of capital investment will become an uncertainty element in the future planning.

The multiobjective optimization methodology has been developed and applied by choosing three objective functions derived from Government of Indonesia (GOI) energy policy i.e.: minimum total cost (f_1), maximum use of coal (f_2), minimum environmental impact (f_3).

MULTIOBJECTIVE OPTIMIZATION: A BASIC CONCEPT OF METHODOLOGY.

In electric power expansion within the framework of energy policy, there are many factors such as natural resources and environmental impact which are conflicting and sometimes even oposing mutually. Therefore the optimization for such a system must be done from various point of view not only a single point of view like economic efficiency.

This type of optimization problem can often be described as a multiobjective optimization problem. In general, such a problem has a set of innumerable solutions which is called non-inferior solutions. (3).

It is often important for a decision maker to select one solution, i.e. preference solution which is acceptable to him from the non-inferior (efficient) optimal set. In this study we introduce the concept of penalty factor γ to represent the value of trade-offs between objective function f_1 (min, cost) and objective function f_2 (max. use of coal). In other words penalty factor γ and also be considered as a value of trade-off to to represent the secrificing of total cost (Δf_1) which can be offered to to get additional increased use of coal (Δf_2).

Method of Problem Solving.

1). The non-inferior solution is obtained by solving parametrically equation (1), and solution for multiobjective linier programming model are illustrated by trade-off curve of two objectives (f_1 v.s. f_2), keeping f_3 as a bounded parameters.

$$f_1(x) - (1 - \alpha) f_2(\underline{x}) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$s/t : \underline{X} \in Td\{x \mid g(\underline{x}) \leqslant 0\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$\text{lower} \leqslant f_3(\underline{x}) \leqslant \text{upper} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

(2) Objective function f_3 (environmental imnpact) is treated as a constraint which has the upper and the lower boundary (see equation (3), consisting of 3 categories i.e.: low (L), medium (M), high (H) environmental impact.

(3) The prefered (optimum) solution for each category is obtained by applying the concept of penalty-factor γ as defined above. Since additional increase use of coal will tend to decrease the use of coil, factor γ can be considered as a penalty factor influenced by oil price in market.

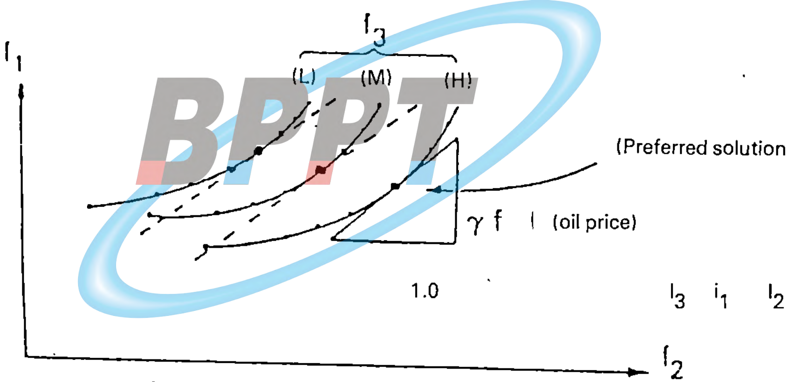

Fig. 1. Trade offs curve & penalty factor γ

For the problem shown above (equation (1), (2) & (3) the following theorema and lemma are significant:

Theorema — 1: Geoffrion [2]

(i) Min $f_1(\alpha)$ and Max. $f_2(\alpha)$ as shown in equation (1) is monotonically non-decreasing on $\alpha \in [0,1]$.

(ii) Any solution $\underline{x}(\alpha)$ of equation (1) is a non-inferior solution if α is in $0 \leqslant \alpha \leqslant 1$.

Lemma — 1 :

$$\Delta f_1 < \Delta f_2 * \gamma f \text{ (oil price)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

$$f \text{ (oil price)} = \frac{\delta f_1}{\delta f_2} > 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where : γ is a penalty factor influanced by oil price in the market.

f_1 can be considered as domestic currency (Rp.).

f_2 can be considered as foreign currency ($).

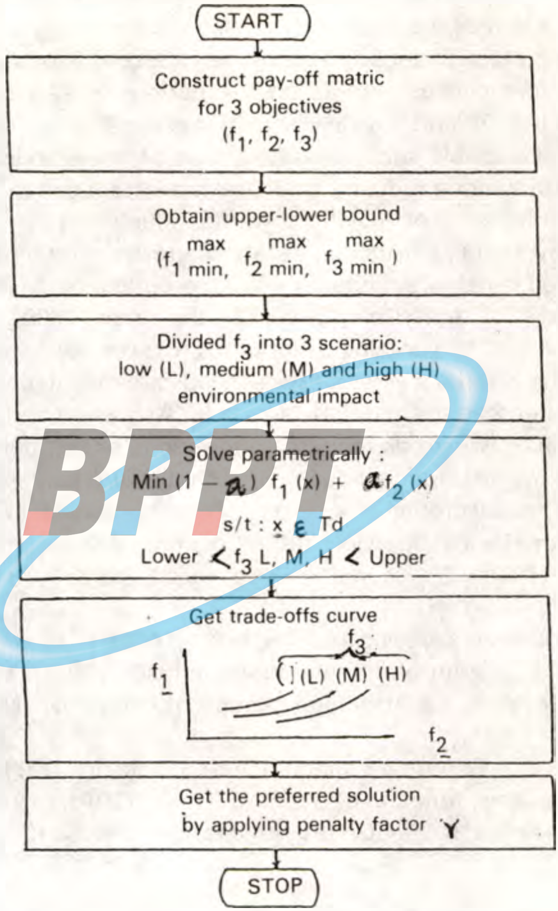

Fig. 2. The algorithm for multiobjective optimization.

ELECTRICITY DEMAND.

Framework of the Demand Model.

Since a demand forecast is greatly depended on variables incorporated with the macroeconomy, we use regression model to describe economic system.

The electricity demand for the residential & commercial (RCEL) and industrial (INEL) sectors, has been estimated by regresing historical data of electricity and macroeconomy variables such as: GDP, private consumption expenditure (HHEX), value-added of manufacturing industry (MFIO), value-added of heavy industry (CCISO).

The future growth of electricity demand will be determined not only by the gross output of productivity, but also will be strongly influenced by the demand structural change. To grasp the impact of structural change on the electricity demand as well as on the pattern of system load factor (LOADF) beside GDP and private consumption expenditure (HHEX), other macroeconomic variable such as value added of heavy industry (CCISO) and total manufacturing industry (MFIO) were introduced into the model.

One consequence of moving towards industrialization is a growing need for energy; more kwh/capita, a state where in the dominant job group is that employed in manufacturing or making products out of raw materials. A major study of Indonesia Towards the Year 2000, by Sumitro Djojohadikusumo (7), contains projections of the long range growth prospects of the country's economy which indicate manufacturing industry will expand faster than the economy as whole. At present agriculture forms 30% of the GDP, where as manufacturing industry just only 15% The anticipation of manufacturing industry contribution will be 25% by the year 2000, with the annual growth around 9% . This projection is incorporated in the demand model by applying rather high growth of manufacturing industry: 9.0% $\sim$ 9.5% compare with only: 5.0% $\sim$ 5.5% of GDP growth.

Two scenarios are applied into the demand model:

- Scenario 1: growth of manufacturing industry (MFIO) as exogenous variable to allow the structural change of economy. (MFIO growth: 9.5%).
- Scenario 2 : Growth of manufacturing industry (MFIO) as endogenous variabel, function of GDP (MFIO = f (GDP).

In both cases as 5.5% GDP growth has been choosen.

Lemana 2 :

(i) The increasing growth of electricity consumption in the light industrial sector will tend to improve the power system load-factor;

(ii) Meanwhile the increasing growth of electricity consumption in the residential sector as well as in the heavy industrial sector will influence the peak load, and eventually will decrease the load-factor.

Lemma 2 has been proven through various testing of the model and result of simultions are shown in Fig. 3.

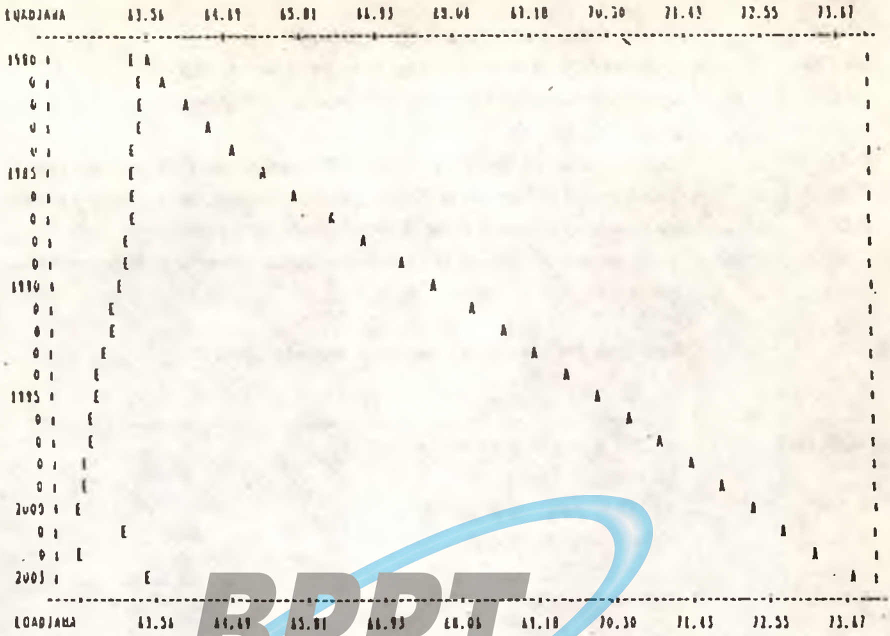

Fig. 3. Load Factor (Jawa Island) for Scenario 1 (A) and Scenario 2 (E).

Equation for sub macro-economic model (Tabel 1).

(1) HHEX	=	Exp. (−0.63153 + 0.69846*Log (GDP) + 0.35262*Log. (HHEX (−1).
(2) DMFIO	=	−200.42 + 0.72695 E−01*GDP + 0.65118*DMFIO (−1).
(3) DCCO	=	−28.004 + 0.42040 E−01*GDP 0.62114*DCCO (−1)
(4) DISO	=	−14045 + 0.21735 E−03*GDP.
(5) CCO	=	(DCCO/DMFIO) * MFIO.
(6) (ISO)	=	(DISO/DMFIO)*MFIO.
(7) CCISO	=	CCO + ISO + ISO.

Where :

HHEX	=	Private Consumption Expenditure (Billion Rupiah).
DMFIO	=	Dummy GDP of Manufacturing Industry (Billion Rupiah).
DCCO	=	Dummy value-added of Cement & Ceramic (Billion Rupiah, 1973 constant price).
DISO	=	Dummy value-added of Iron & Steel (Billion Rupiah, 1973 constant price).
CCO	=	Value-added of Cement & Ceramic (Billion Rupiah, 1973 constant price).
ISO	=	Value-added of Iron & Steel (Billion Rupiah, 1973 constant price).
CCISO	=	Value-added of Cement & Ceramic + Value-added of Iron & Steel (Billion Rupiah, 1973 constant price).

Equation for electricity demand model (Tabel 2).

RCELWIT	=	−2271.4 + 0.81307 * HHEX
		(−17.0) (39.0)
R * R	=	0.9974 (0.9967); D.W = 2.5
		INTV = (1974 − 1980).
RCELWIT	=	−2044.4 + 0.72022 * HHEX
		(−8.6) (19.3)
R * R	=	0.9894 (0.9967); D.W = 1.5
		INTV = (1974 − 1980)
INELWIT	=	−1297.2 + 5.6533 * MFIO
		(−3.5) (16.4)
R * R	=	0.9818 (0.9782); D.W = 1.5
		INTV = (1974 − 1980)
INELWJT	=	−1925.8 + 3.9473 * MFIO
		(−5.8) (12.9)
R * R	=	0.9707 (0.9649) ; D.W = 1.2
		INTV = (1975 − 1981)
HINELWJT	=	10.295 + 15.172 * (CCO − ISO)
		(0.2) (7.9)
R * R	=	0.9264 (0.9117); D.W = 2.0
		INTV = (1975 − 1981)
PKELWJT	=	−120.07 + 0.37647 * (RCELWJT + HINELWJT)
		(−2.0) (16.9)
R * R	=	0.9828 (0.9793) ; D.W = 1.5
		INTV = (1975 − 1981)

PDELWJTT	=	42.756 + 1.3624 * (INELWJT + RCELWJT)
		(0.3) (33.8)
R * R	=	0.9956 (0.9948) ; D.W = 2.2
		INTV = (1975 — 1981)

Where :

RCELWIT	=	Electricity demand in residential/commercial sector for Indonesia (GWh)
RCELWJT		Electricity demand in residential/commercial sector for Jawa Island only (GWh).
INELWIT	=	Electricity demand in manufacturing industry sector for Indonesia (GWh).
INELWJT	=	Electricity demand in manufacturing industry sector for Jawa Island only (GWh).
HINELWJT	=	Electricity demand in heavy industry sector for Jawa Island only (GWh).
PKELWJT	=	Peak-load for Jawa Island System (MW).
PDELWJT	=	Production of electricity in Jawa Island (GWh).

Tabel 3

Scenario for G.O.I. Five Year Development Plan (Repelita V, VI, VII & VIII)

Scenario — 1	**End of Repelita**				
	III (Actual)	**IV (1988)**	**V (1993)**	**VI (1998)**	**VII (2003)**
1. Growth of GDP (%)	4.2	5.0	5.5	5.5	5.5
2. Growth of Manufacturing Industry (%)	2.2	9.0	9.5	9.5	9.5
3. Contribution of Manufacturing Industry to GDP (%)	15.1	17.1	21.4	25.7	31.0
4. Electricity Consumption (GWh), Growth (%)	15539 (12.7)	22475 (8.9)	34783 (9.1)	53590 (9.0)	82121 (8.9)
Percentage of use in Manufacturing Industry	58.0	65.0	68.0	70.8	78.6
Percentage of use in residential & commercial	42.2	35.0	32.0	29.2	21.4
5. Consumption per capita (KWh)	98.7	128.0	178.8	249:5	346.2
6. Elasticity of Growth to GDP	3.0	1.78	1 65	1.64	1.62
7. Load factor for Jawa Island (%)	68.0	66.67	69.10	71.38	73.76

Scenario – 2	End of Repelita				
	III (Actual)	IV (1988)	V (1993)	VI (1998)	VII (2003))
1. Growth of GDP (%)	4.2	5.0	5.5	5.5	5.5
2. Growth of Manufacturing Industry (%)	2.2	6.3	6.4	6.2	6.0
3. Contribution of Manufacturing Industry to GDP (%)	15.1	15.5	16.2	16.9	17.4
4. Electricity Consumption (GWh), Growth (%)	15539 (12.7)	20474 (6.9)	28803 (6.9)	40084 (6.6)	54979 (6.4)
Percentage of use in Manufacturing Industry	58.0	61.5	61.2	60.1	60.1
Percentage of use in Residential & Commercial	42.0	38.5	38.8	39.9	39.9
5. Consumption per capita (kWh)	98.7	116.6	148.0	186.6	231.8
6. Elasticity of growth to GDP	3.0	1.30	1.25	1.20	1.16
7. Load factor for Jawa Island (%)	68.0	63.31	62.95	62.65	52.54

Relation between Load Duration Curve and Structural Change of Demand.

The fifth order polinomial relationship to express the shape of the load duration curve developed by A.J. Snyder (6), indicated that the ratio of minimum to maximum load during the period (α) and the ratio of average to maximum load are in general closely related to the coefficients of the 5th order polinominal.

The following equation can be used:

$$Y = 1 + 6(3\beta - \alpha - 2)X + (-82\beta + 27\alpha + 55)X^2 + 4(38\beta - 10\alpha - 28)X^3 + 20(-6\beta + \alpha + 5)X^4 + 32(\beta - 1)X^5)$$

Where :

Y	=	fraction of peak load
α	=	ratio of the min. to max. load
β	=	ratio of the average to max. load (load factor)
X	=	fraction of time.

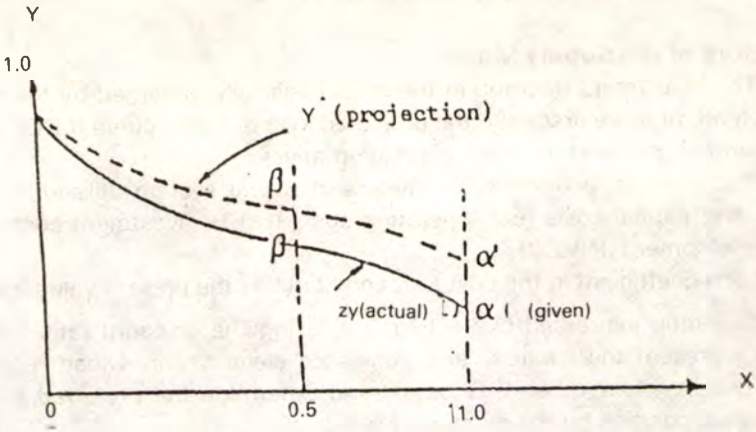

Fig. 4. Load Duration Curves.

If Y = 1.0 is called peak load, then Y = α can be seen as upper bounds of base load, which in this study was estimated as percentage share of heavy industrial demand.

Mean-while β as the ratio of average to maximum load can be considered as load factor, which was found as an endogeneous variable, output of our demand model.

$$\alpha' = \frac{\text{\% share of HINEL}}{\text{\% share of HINEL}} * \alpha \text{ (given)}$$

Tabel 4

Projection of Load Factor and Minimum Load

(Scenario – 1)

Planning Period (ρ)	Load Factor (β)	Ratio Min. Load to the Pek Load (α)
1982 (actual)	0.641	0.420
1988	0.666	0.437
1993	0.691	0.452
1998	0.713	0.465
2003	0.736	0.480

ELECTRIC GENERATION EXPANSION PLAN.

Structure of the Supply Model.

The investment decision in the model basically governed by the projected load, or more precisely, the projected load duration curve (LDC), and the economic parameters of the plant alternatives.

The principal economic parameters of power system utilised in this model are: capital costs (cc), operating costs (cc) & investment costs for coal development (INVCC).

Each coefficient in the cost function contains the present value transformation ratio expressed by $1/(1+r)^{-p}$, using the discount rate r. The model represent the capacity and generated electricity in 4 load regions (peak middle–1, middle–2 & base), and determine the preferred (non-dominated) solution for the criteria specified.

The time horizon is devided into (p) = 1988, 1993, 1998 & 2003 periods each of five years duration, and the power plant (i) are grouped in term of the primary source of energy: (1 = coal), 2 = oil, 3 = gas, 4 = geothermal, 5 = hydro, 6 = nuclear).

There criteria (objectives) derived from GOI energy policy are: (1).economic cost, (2).resources (coal usage), (3).environmental impact.

The decision variables are:

* X_{ipj} = Total Power Capacity (MW); i, p, j.

* Y_{ipj} = Total Energy Generated (GWII); i, p, j.

* Z_{kp} = Coal Consumption; $\forall$ K, p.

Where: i = generation type, p = planning period, l = load area (block), j = island (region), k = coal type.

Objective Function.

Min. Total Cost (f_1)

$$\text{Min. } F_1 = \sum_i \sum_p \sum_j (CC_{ip} \cdot \Delta X_{ipj} + OC_{ip} + Y_{ipj}) \cdot$$

$$(1+r)^{-p} + \sum_k \sum_p \sum_j (\Delta Z_{kpj}\, INVCC_{kp}) \cdot (1+r)^{-p}$$

Max. Use of coal (f_2)

$$\text{Min. } F_2 = \sum_k \sum_p Z_{kp}$$

Min. Environmental Impact (f_3)

$$\text{Min. } F_3 = \sum_i \sum_p \sum_j (E.I.)\, Y_{ipj}$$

Where :

CC_{ipj} = Capital Cost $\forall i, p, j$

OC_{ipj} = Operating Cost $\forall i, p, j$

$INVCC_{kp}$ = Investment Cost for Coal Development Yk,p

$INVCC_{kp}$ = Investment Cost for Coal Development $\forall k,p$

$D.I_{ip}$ = Environmental Impact Coefficient $\forall i, p$

Constraints & Relation.

Power Demand has to be satisfied at all times

$$_i X_{ipj} \geq PD_{pj} ; \forall p,j$$

PD = Power Demand (MW)

Energy Demand has to be satisfied at all times

$$\sum_i Y_{ipj} \geq ED_{pj} ; \forall p,j,$$

ED = Energy Demand (MW)

Operation Constraint

$$\sum_i Y_{ipj1} \leq a_{i1} \cdot t_{1p} \cdot X_{ipj} ; \forall i,p,1.$$

j = 1, ..., 5.

The energy generated from any type of plant cannot exceed the production capacity multiplied by the appropriate duration hour (t) and availability factor (α) at each load duration region (block).

Constraints (7) & (8) imply that each generation plant has different upper limits of availabilities according to their operation styles.

Relation between gen. out-put & coal consumption

$$Y_{ip} = \sum_{k-1}^{k-5} Z_p / n_k$$

n_k = Conversion factor to get IMWH electricity from particular coal type.

Coal availability constraints

$$Z_{kpj} \leqslant CR_{kp} ; \forall_{k,p}$$

$$X_{ipj} \cdot CF_{ip} \leqslant \sum_{k=1}^{3} CR_{kp}/n_k ; i = 1$$

CR = Coal availability : CF Capacity factor.

Hydro & Geothermal Potensial Energy Constraints

$$Y_{4pj} \leqslant GR_{4pj} ;$$

GR = Geothermal Energy availability

$$Y_{5pj} \leqslant HR_{5pj} ;$$

HR = Hydro energy availability

Rate of Growth constraints

$$X_{ip} \leqslant a X_{ip-1}$$

a = rate of growth of capacity expansion.

Decision Criteria f... Multiobjective Analysis.

The three criter... expressed in the preceding section, namely: cost, use of resource (coal) and environmental impact are all considered significant.

Environmental impact, as implied here, relates to air pollution and land use of individual primary: energy source. Coal plants are notorious for their air pollution property while geothermal and hydro plants cover large areas of land. Under normal operation conditions, nuclear plants have very radioactive emission, and they use less land area compared with either type of plants.

As it is difficult to quantify the impact of different types of power plants as well as to determine tha trade-offs between various impacts inherent in each of them, a sensitivity analysis was carried out on environmental impact coefficients in the objective function.

Tabel 5

Environmental Impact Coefficient used in Sensitivity Analysis.

Gen. Type	A	B	C
Coal	5.0	3.0	1.5
Oil, Cas	4.0	2.5	1.4
Geothermal	3.0	2.0	1.3
Hydro	2.0	1.5	1.2
Nuclear	1.0	1.0	1.1

In generating system expansion alternatives, the following procedure is observed :

(a) Two strategies of oil capacity expansion rate of growth (1.4 and 1.1) were chosen.

(b) Three "Scenarios" for low, medium and high environmental impact were defined.

(c) For each strategy the trade-offs curve between specific objectives (cost v.s. use of coal) were established, keeping environmental impact as bounded parameters.

(d) All together six cases of expansion alternatives can be chosen among the non-inferior solutions visualised to the decision maker by the six trade-offs curve between specific objectives (cost v.s use of coal) were established, keeping environmental impact as hounded parameters.

(d) All together six cases of expansion alternatives can be chosen among the non-inferior solutions visualised to the decision maker by the six trade-off curves.

Computational Result of Supply Model.

The computation were executed by using Kaya Lab. (Tokyo University) program system, run on IBM 370 computer (IPTN Bandung).

In our supply model the base year is 1983 consisting of 4 planning period (5 years for each period) and the termination of planning period will be in 2003, last year of REPELITA VII.

As a model with multiobjective approach the outcome of the model will consist of some alternatives which are chosen among the non-inferior solutions. In this multiobjective model we propose a simple method by which the decision maker can easily determine his preference solution. This method compute the trade off curve between the two specific objectives one by one parametrically.

The trade-off curve is presented to the decision maker graphically so that by applying concept of penalty factor γ , a value trade-off to represent the sacrifice of total cost (Δf_1) to get additional increased use of coal (Δf_2), he can determine one most preferable solution on the curve.

As mentioned before two strategies of oil capacity expansion rate of growth (1.4 and 1.1) have been chosen and for each of it three "scenarios" for low, medium and high environmental impact were defined. So that all together six cases expansion alternatives can be chosen from six trade-off curves.

Tabel 6 (a) and (b) shows low environmental impact scenario of the capacity expansion (MW) and coal development plan (ton) in Jawa Island for strategy II, while Tabel 5 (c) shows minimum cost (single objective) alternative.

Tabel 6.

Capacity Expansion (MW) Jawa Island

Low Environmental Impact (L)

(a) Strategy I

	1988	1993	1998	2003'
Coal	1004	2388	4237	7132
Oil	1820	2548	3567	4993
Gas	820	1149	1608	2251
Geothermal	180	450	1125	2000
Hydro	1645	1645	1645	1645
Nuclear	0	0	0	0
Total (MW)	5469	8180	12102	18021
Coal Consump (10E3 Ton)	17	4270	11848	16229

(b) Strategy II

	1988	1993	1998	2003
Coal	1394	3363	6073	8519
Oil	1430	1573	1730	1903
Gas	820	1149	1608	2251
Geothermal	180	450	1125	2000
Hydro	1645	1645	1645	2108
Nuclear	0	0	0	1240
Total (MW)	5469	8180	12181	18021
Coal Consump (10E3 Ton)	2440	5976	13437	19822

(c) Minimum Cost Alternative

	1988	1993	1998	2003
Coal	1394	3363	3873	4845
Oil	1430	1573	1730	1903
Gas	820	1149	1608	2251
Geothermal	180	450	1125	2000
Hydro	1645	1645	1645	2622
Nuclear	0	0	2200	4400
Total (MW)	5469	8180	12181	18021
Coal Consump (10E3 Ton)	2058	5214	7373	8993

5 CONCLUSION.

(1) A review of electric power supply-demand has been presented covering in board outline the following aspects:

- energy demand and its structural change in Indonesia.
- use of computer-aided methodology for planning and analysis.

* the likely future developments in Indonesia generating capacity along with its primary energy resources option.

(2) Electricity demand in the future will be characterised as follow:
* growth rate of demand will tend to decrease following the moderate growth rate of GDP in future.
* electricity demand in manufacturing industrial sector will growth faster than the demand in residential & commercial sector, consisted with the prospect of the countries economy which indicated that manufacturing industry will expend faster than the economy as a whole.
* decreasing of growth rate demand in residential & comm. as well as demand in heavy industry have resulted on decreasing of peak load growth rate, and eventually improve the system load factor in Jawa Island (scenario—2).

(3) With the contribution of manufacturing industry to GDP reach 25.7 at the end of REPELITA VI (1998) scenario—1 can be considered as a more suitable condition for G.O.I. industrialization program. By that time (1998) electricity production is 73980.3 GWH with consumption per capita reachs amount of 249.5 KWH. Contribution of electricity consumption in manufacturing industry shows the figure of 78.6 with growth 10.3 annually.

(4) With the high growth of electricity demand in manufacturing industry, power system load-factor will tend to improve (± 0.70 in the year 2000) for scenario—1, meanwhile for scenario—2, with growth of manufacturing industry as an endogenous variable influenced by GDP, value of load-factor will fixed around figure 0.60.

(5) Generating capacity expansion strategy which allow or tolerate oil thermal plant to expand (Strategy II) will become suitable alternative under uncertainty and my avoid a vary steep growth of coal consumption, which means reducing the environmental problem.

(6) Coal power plants will contribute significantly in the future planning, but its role will be restricted by oil price and its environmental problems.

(7) Application of nuclear energy for electric power system expansion toward the year 2003 in Indonesia is not a very cruisial decision (only 1200 MW for low environmental impact scenario).

(8) The modelling technique and the solution procedure employed in this study yield reliable results even when only qualitative information exist; hence it is possible to accomodate dimensions which are otherwise difficult to model.

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