

**GENERAL TRAINING
MANUAL
FOR THE LONG-TERM
PLANNING MODEL**

Economic Cost versus Accounting Cost

“An economist thinks of cost differently from an accountant, who is concerned with the firm’s financial statements. Accountants tend to take a retrospective look at a firm’s finances because they have to keep track of assets and liabilities and evaluate past performance.

Economists take a forward-looking view. They are concerned with what cost is expected to be in the future, and how the firm might be able to rearrange its resources to lower its cost and improve its profitability. They must therefore be concerned with opportunity cost, the cost associated with opportunities that are foregone by not putting the firm’s resources to their highest value use.” [

Opportunity Cost

The benefit foregone by using a scarce resource for one purpose instead of for its next best alternative use.

An *opportunity cost* is incurred because of the use of limited resources, such that the opportunity to use those resources to monetary advantage in an alternative use is foregone. Thus, it is the cost of the best rejected (i.e., foregone) opportunity and is often hidden or implied.

Opportunity Cost (continued)

Example:

Suppose that a construction project involves the use of a storage space presently owned by a company. The cost for that space to the project should be the income or savings that possible alternative uses of the space may bring to the company. In other words, the opportunity cost for the space should be the income derived from the best alternative use of it. This may be more than or less than the average cost of that space obtained from the accounting records of the company.

Marginal Cost

An *incremental or marginal cost* is the additional cost, or revenue, that results from increasing the output of a system by one (or more) units.

Marginal cost is often associated with “go/no go” decisions that involve a limited change in output or activity level.

For instance, the incremental cost per mile for driving an automobile may be \$0.27, but this cost depends on considerations such as total mileage driven during the year (normal operating range), mileage expected for the next major trip, and the age of the automobile.

Marginal Cost (continued)

Also, it is common to read of the “incremental cost of producing a barrel of oil.” The incremental cost (or revenue) is often quite difficult to determine in practice.

With electricity generation the marginal cost is a function of how much advance notice is given for demand. One additional MW in a minutes time horizon is a very different cost to an additional MW in one months time.

Short-Run Costs

Rate of Output	Fixed Cost (FC) (1)	Variable Cost (VC) (2)	Total Cost (TC) (3)	Marginal Cost (MC) (4)	Average Fixed Cost (AFC) (5)	Average Variable Cost (AVC) (6)	Average Total Cost (ATC) (7)
0	50	0	50	-	-	-	-
1	50	50	200	50	50	50	100
2	50	78	128	28	25	39	64
3	50	98	148	20	16.7	32.7	49.3
4	50	112	162	14	12.5	28	40.5
5	50	130	180	18	10	26	36
6	50	150	200	20	8.3	25	33.3
7	50	175	225	25	7.1	25	32.1
8	50	204	254	29	6.3	25.5	31.8
9	50	242	292	38	5.6	26.9	32.4
10	50	300	350	58	5	30	35
11	50	385	435	85	4.5	35	39.5

Sunk Cost

A cost incurred in the past that cannot be retrieved as a residual value from an earlier investment. It is not an opportunity cost. In economics the sunk cost is equivalent to fixed cost in short-term decision making.

Sunk Cost (continued)

A classic example of sunk cost involves the replacement of assets. Suppose that your firm is considering the replacement of a piece of equipment. It originally cost \$50,000, is presently shown on the company records with a value of \$20,000, and can be sold for an estimated \$5,000.

For purposes of replacement analysis, the \$50,000 is a sunk cost. However, one view is that the sunk cost should be considered as the difference between the value shown in the company records and the present realizable selling price. According to this viewpoint, the sunk cost is \$20,000 minus \$5,000, or \$15,000. Neither the \$50,000 or the \$15,000, however, should be considered in an engineering economic analysis – except for the manner in which the \$15,000 may affect income taxes.

Market Price

The market price is the price at which a good or service is actually exchanged for another good or service (as an in kind payment) or for money (in which case it is a financial price).

Example:

The market clearing price of electricity in a power pool is the price at which the most expensive unit is dispatched to meet demand. The results from the Purdue power pool model gives a pattern of expansions that occur if a tight power pool were to operate a power exchange, where every hour, a market clearing price was set.

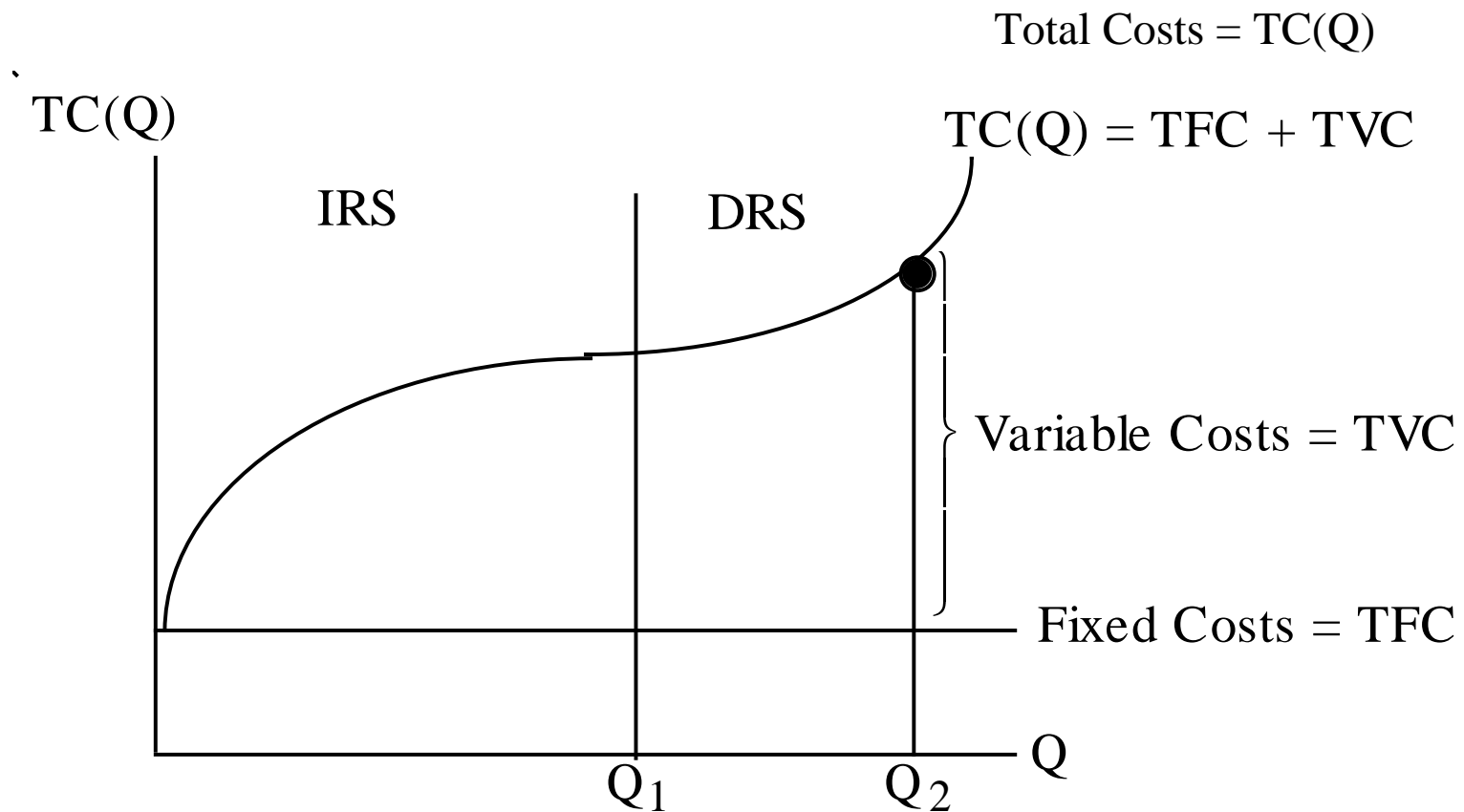
Shadow Price

Shadow price technically implies a price that has been derived from a complex mathematical model (for example, from linear programming).

Capital Recovery Factor (crf)

The annual payment that will repay a loan of 1 currency unit in “n” years with compound interest on unpaid balance – permits calculating equal installments necessary to repay (amortize) a loan over a given period at a stated interest rate “i”. Such that: $crf = i(1+i)^n / [(1+i)^n - 1]$

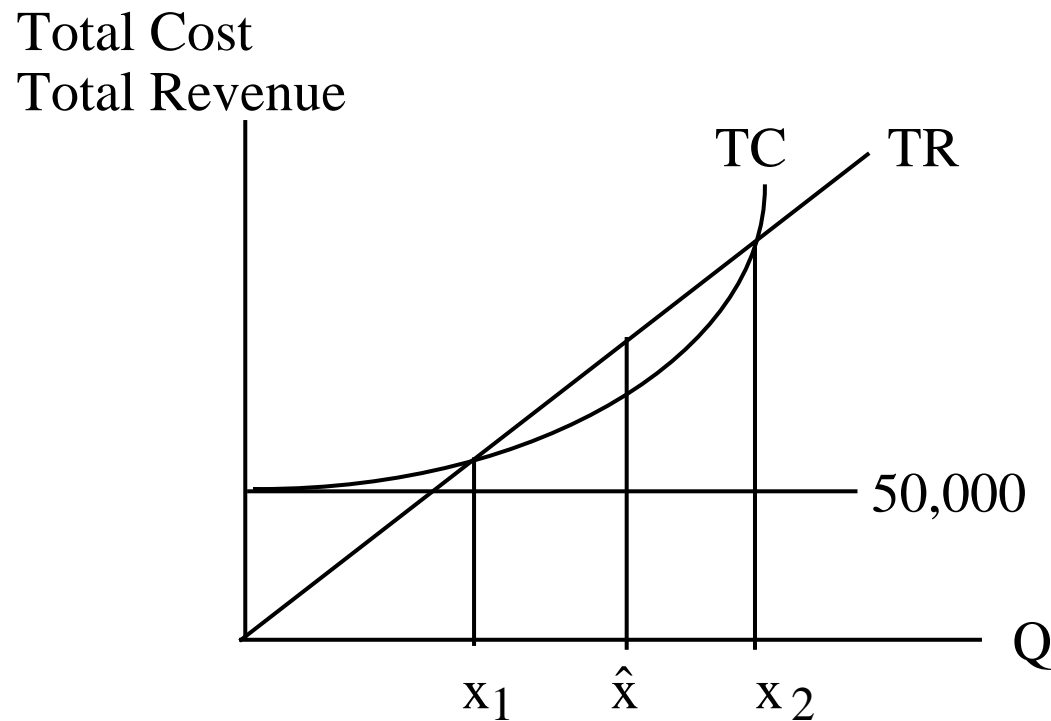
Average (“Unit”) Costs are Usually Misleading Guides to Choosing Between Alternatives; What’s Important are Marginal, or Incremental, Costs



IRS = increasing returns to scale; DRS = decreasing returns to scale.

Marginal Costs are What are Critical in Decision-making, Not Average Costs

Price = \$35/unit, Cost = 50,000 + 20.2x + 0.0001x²



What x maximizes profit? $\pi \max \rightarrow 35 - 20.2 - 0.0002x = 0$

$$\rightarrow = \frac{14.8}{0.0002} = 74,000$$

Operations Research

Example 1:

Consider the unit commitment problem and the options again but this time there are two generating stations, one thermal and one hydropower. The thermal station has two generating units and in the hydropower station there is one unit. How many options or combinations of switched-on units are available during one time period?

Operations Research

Example 1 continued

Option No:	1	2	3	4	5	6	7	8
Condition:	On/Off	On/Off	On/Off	On/Off	On/Off	On/Off	On/Off	On/Off
Unit 1	0/1	1/0	0/1	0/1	1/0	1/0	0/1	1/0
Unit 2	0/1	0/1	1/0	0/1	1/0	0/0	1/0	1/0
Unit 3	0/1	0/1	0/1	1/0	0/1	1/0	1/0	1/0

With this simple example, in one time period (say one hour), there are already 8 different options available.

With 2 conditions and 3 units there are:

$$2^3 = 8 \text{ possible operating options available.}$$

Operations Research

Example 2:

Consider the example above again but this time let there be two time periods called hour 1 and hour 2.

In hour 1 there is option 1 and following in hour 2 there would be 8 options.

In hour 1 there is option 2 and following in hour 2 there would be 8 options.

In hour 1 there is option 3 and following in hour 2 there would be 8 options.

Etc. etc.

In hour 1 there is option 8 and following in hour 2 there would be 8 options.

Operations Research

Example 2 continued

With a second time period being involved there are now 64 possible operating options to consider. The complexity of the problem increases exponentially.

There are now $2^3 \times 2^3 = 64$ conditions.
 $2^6 = 64$

In one day with 24 one hour time periods the number of operating options available will be equal to:

$$\begin{aligned}2^{3 \times 24} &= 2^{72} \\2^{72} &= 4.722366483 \times 10^{21} \\2^{72} &= 4,722,366,483,000,000,000,000 \\&= 4,722 \text{ trillion trillion options}\end{aligned}$$

Thus a relatively simple problem can quickly involve an unmanageable number of options.

Introduction to GAMS

We are given the supplies at several markets for a single commodity (electricity) at a single point in time. We are given the unit costs of shipping the commodity from plants to markets. The economic question is how much shipment should there be between each plant and each market so as to minimize the total shipment cost?

<i>Markets</i>					
	Harare		Lusaka	Pretoria	<i>Supplies</i>
					<i>(MWh)</i>
<i>Plants</i>	<i>Wheeling Distances</i>				
	<i>(Thousands of miles)</i>				
Inga	1.6		1.3	2.2	2100
HCB	0.3		0.6	1.0	1600
<i>Demands</i> <i>(MWh)</i>	700		400	2500	

SETS - Indices

i = plants, j = markets

PARAMETERS, TABLES, SCALARS - Given Data

H_i = supply of commodity at plant i (MW)

D_j = demand for commodity at market j (MW)

C_{ij} = cost of MW shipping/wheeling to ship from plant i to market j (MW)

DECISION VARIABLES

X_{ij} = quantity of commodity to ship from plant i to market j (MW)

Where $X_{ij} \geq 0$ for all i,j

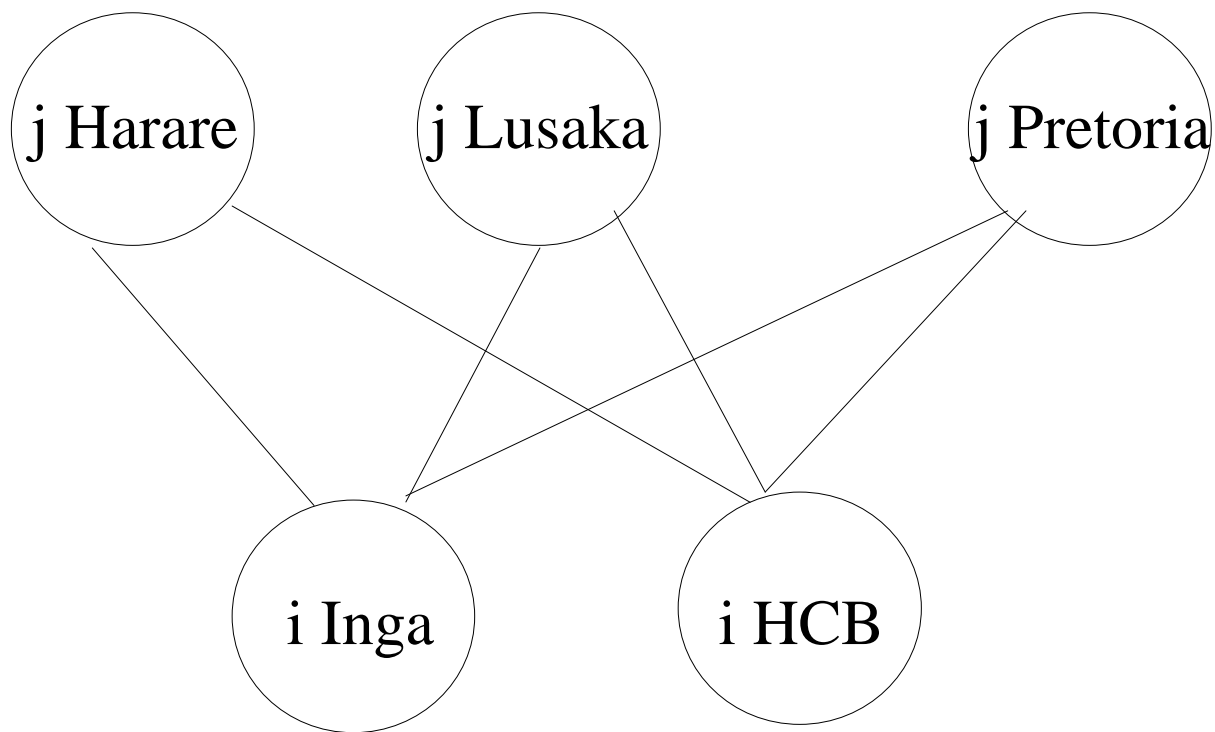
EQUATIONS – COST, SUPPLY & DEMAND must be declared.

MODEL Supply limit at plant i $\sum_j X_{ij} \leq H_i$

Satisfy demand at market j $\sum_i X_{ij} \geq D_j$

Objective Function

Minimize $\sum_i \sum_j C_{ij} X_{ij}$



Shipping costs are approximately \$2 per MWh per thousand miles.

GAMS FORMAT

```
SET      I      Generation plants /      Inga, HCB /;
SET      J      Demand Centers      /      Harare, Lusaka, Pretoria      /;

PARAMETER H(I)      Exporting capacity (MWh) of plant I
/
              Inga 2100
              HCB 1600 /;

PARAMETER D(J)      Demand (MWh) at Market J
/
              Harare 700
              Lusaka 400
              Pretoria 2500      /;

TABLE L(I,J)      Distance in thousands of miles from I to J
              Harare      Lusaka      Pretoria
Inga      1.6      1.3      2.2
HCB      0.3      0.6      1.1      ;
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GAMS FORMAT (continued)

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SCALAR          W          Wheeling charge in $ per thousand miles / 2 /;

PARAMETER C(I,J);
              C(I,J) = W*L(I,J);

VARIABLE        X(I,J)     Shipment quantities in MWh
VARIABLE        Z          Total shipment cost in thousands of $

POSITIVE VARIABLE X ;

EQUATION        COST          Define objective function
EQUATION        SUPPLY(I)    Observe supply limit at plant I
EQUATION        DEMAND(J)    Satisfy demand at market J ;

                                COST..          Z =E= SUM((I,J),C(I,J)*X(I,J))
                                SUPPLY(I)..      SUM(J,X(I,J)) =L= H(I)
                                DEMAND(J)..      SUM(I,X(I,J)) =G= D(J)

MODEL  ELEC          /          ALL          /
SOLVE  ELEC USING LP  MINIMIZING Z ;
DISPLAY X.L, X.M

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GAMS OUTPUT

ITERATION COUNT, LIMIT 6 10000
Cplex 6.0, GAMS Link 12.0-7, 386/486 DOS
Optimal solution found.

Objective : **10480.000000**

VAR X	Shipment quantities in MWh			MARGINAL
	LOWER	LEVEL	UPPER	
Inga.Harare	.	.	+INF	0.400
Inga.Lusaka	.	400.000	+INF	.
Inga.Pretoria	.	1600.000	+INF	.
HCB .Harare	.	700.000	+INF	.
HCB .Lusaka	.	.	+INF	0.800
HCB .Pretoria	.	900.000	+INF	.

Existing and Proposed Generation Stations

Country	Station Name	Details of Station
Country1	PG(1A)	Existing thermal station, 1200MW
-	PG(1B)	Existing thermal station, 1600MW (expansion is possible up to 2500MW, costing \$0.5m/MW)
-	NH(1C)	Proposed new hydro station of 900MW with fixed cost \$600m for the first 300MW and then a variable cost of \$0.9/MW
-	NH(1D)	Proposed new hydro station of 600MW with a fixed cost of \$850m
-	GT(1E)	Proposed new gas turbine station capable of expansion up to 600MW with a variable cost of \$0.3m/MW
Country2	PG(2A)	Existing thermal station, 550MW
Country3	PG(3A)	Existing thermal station, 260MW
-	GT(3B)	Proposed new gas turbine stations capable of expansion up to 600MW with a variable cost of \$0.31m/MW
Country4	PG(4A)	Existing thermal station , 500MW
-	PG(4B)	Existing combined cycle station, 1200MW, with option of expansion up to 2600MW, with a variable cost of \$0.6m/MW
-	CC(4C)	Proposed new combined cycle station, 300MW, with fixed cost of \$175m and then the option of expansion up to 2100MW with a variable cost of \$0.55m/MW
-	GT(4D)	Proposed new gas turbine station, 300MW, with a variable cost of \$0.325m/MW
Country5	PG(5A)	Existing combined cycle plant, 2400MW
-	CC(5B)	Proposed new combined cycle station, 350MW, with fixed cost \$ 405m and then the option of expansion up to 2800MW with a variable cost of \$0.63m/MW
Country6	H(6A)	Existing hydropower station, 600MW
-	NH(6B)	Proposed new hydropower station, 150MW, with fixed cost of \$220m and then the option of expansion up to 900MW with a variable cost of \$1.1/MW
Country7	H(7A)	Existing hydropower station, 450MW
-	NH(7B)	Proposed new hydropower station, 200MW, with fixed cost of \$270m, with the option of expansion up to 600MW at a variable cost of \$1.3m/MW

Existing and Proposed International Transmission Lines

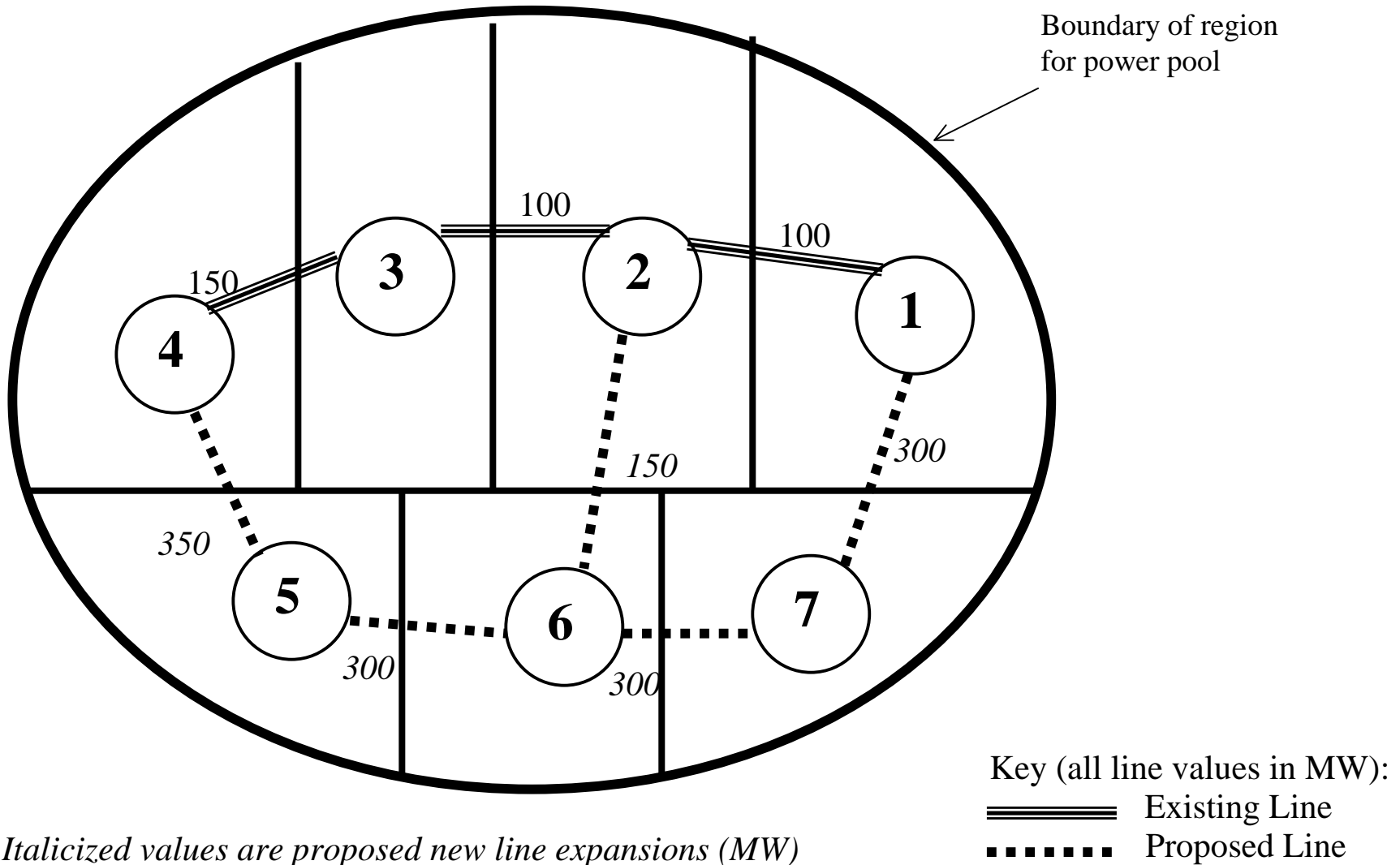
From Country To Country	Interconnector Name	Details of International Interconnector
1 to 2	OT(1-2)	Existing international transmission line with a total load carrying capability of 100MW – can be expanded up to 2000MW at a cost of \$0.2m/MW
2 to 3	OT(2-3)	Existing international transmission line with a total load carrying capability of 100MW – can be expanded up to 2000MW at a cost of \$0.25/MW
3 to 4	OT(3-4)	Existing international transmission line with a total load carrying capability of 150MW – can be expanded up to 2000MW at a cost of \$0.15/MW
4 to 5	NT(4-5)	Proposed new international transmission line with an initial carrying capability of 350MW having a fixed cost of \$100m. This line can be further expanded up to 2000MW with a variable expansion cost of \$0.16m/MW.
5 to 6	NT(5-6)	Proposed new international transmission line with an initial carrying capability of 300MW having a fixed cost of \$40m This line can be further expanded up to 750MW with a variable expansion cost of \$0.22m/MW.
6 to 2	NT(6-2)	Proposed new international transmission line with an initial carrying capability of 150MW having a fixed cost of \$88m This line can be further expanded up to 750MW with a variable expansion cost of \$0.15m/MW.
6 to 7	NT(6-7)	Proposed new international transmission line with an initial carrying capability of 300MW having a fixed cost of \$120m This line can be further expanded up to 2000MW with a variable expansion cost of \$0.25m/MW
7 to 1	NT(7-1)	Proposed new international transmission line with an initial carrying capability of 300MW having a fixed cost of \$95m This line can be further expanded up to 2000MW with a variable expansion cost of \$0.2m/MW

Supplies of Natural Gas in the Generic Model

Country	Existing Supplies of Natural Gas (mmscfd – millions of cubic feet per day)	Proposed Maximum Supplies of Natural Gas (mmscfd)	Combined Cycle Generating capacity, Existing – Proposed (MW)
Country 4	200	790	1200 – 4700
Country 5	60	470	350 - 2800

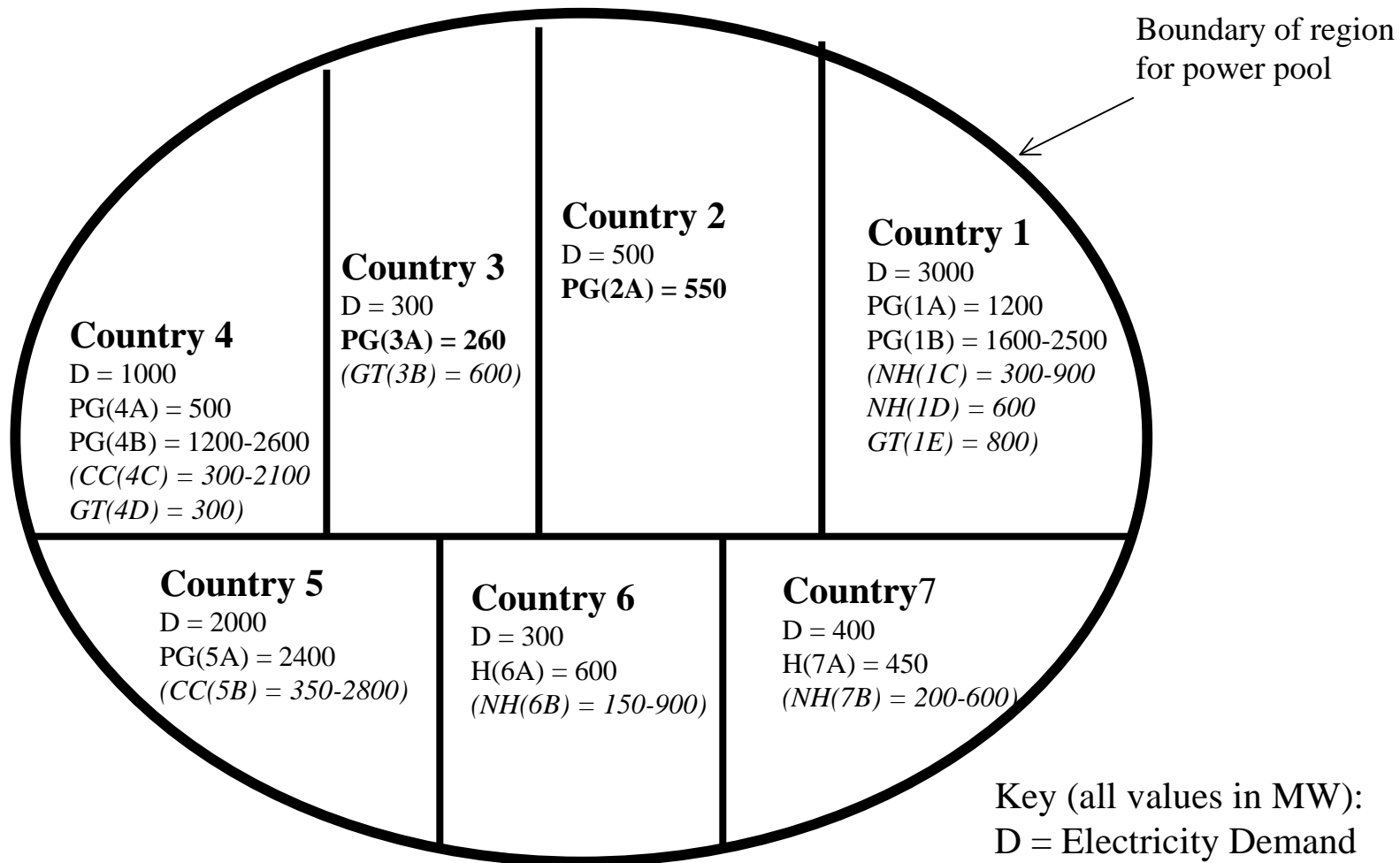
Notes: Assuming that 100mmscfd will generate 600MW of combined cycle. Only Countries 4 and 5 have access to natural gas supplies. The other countries have no natural gas available to them except that a gas pipe-line be built from Country 4 or 5. The generic model in this manual does not provide the option of the expansion of a pipe-line to the other countries.

Training Model with Existing International Transmission Lines and Proposed New Lines



*Italicized values are proposed new line expansions (MW)
All lines can expand up to 2000MW*

Training Model with Peak Demand & Existing Generation for Each Country



(Italicized values are proposed capacity expansions (MW))

Key (all values in MW):
 D = Electricity Demand
 PG = Old thermal/oil generation
 CC = Old Combined Cycle generation
 H = Old hydropower generation

Summary of Projects Selection for the Three Policy Scenarios

-	<i>Scenario #1</i>	<i>Scenario #2</i>	<i>Scenario #3</i>
Total regional cost (\$billion)	5.59	8.07	8.81
Generation Expansions (MW)	-	-	-
Old Thermal	0	900	2300
New Combined Cycle	3150	2575	4955
New Hydropower	1614	1080	1634
New Gas Turbines	462	741	1700
Total:	5226	5296	10589
Transmission Expansion (MW)	-	-	-
Old Transmission	572	4	4599
New Transmission	3460	317	3318
Total:	4032	321	7917