# THE FUTURE OF NUCLEAR POWER IN THE DEVELOPING COUNTRIES

by

Alan M. Strout*

#MIT-EL 77-006WP
April 1977

---

*Lecturer, Department of Urban Studies and Planning, M.I.T. This study was undertaken while the author was a Research Affiliate with the M.I.T. Energy Laboratory.

# The Future of Nuclear Power in the Developing Countries

This paper deals with two questions: How important will nuclear power be to developing countries over the next twenty-five years? and How many developing countries are likely to have constructed nuclear power plants by the year 2000? Each of these questions raises a number of subsidiary questions and issues. These are discussed in turn below. A final section covers the conclusions to be drawn from the discussion.

## The Importance of Energy to Development

This subject is usually approached by means of a chart showing country data for per capita energy consumption plotted against per capita income. When the entire spectrum of rich and poor countries is included on the chart, there is a close relationship between energy use and income. This relationship is interpreted as showing how energy use can be expected to increase as per capita incomes increase.

The implied cross-country statistical relationship is valid, but its use to describe future developments can be wrong for at least four reasons. First, per capita income is almost inevitably measured using official exchange rates to convert national currency into common units, usually U.S. dollars. This procedure exaggerates the purchasing power differences among countries by as much as two or three times for the lower income countries.[1]

---

[1] Irving B. Kravis, Zoltan Kenessey, Alan Heston, and Robert Summers, A System of International Comparisons of Gross Product and Purchasing Power (Baltimore: Johns Hopkins for the World Bank, 1975).

The growth of income over time is usually expressed in terms of constant prices, and this, in turn, is roughly comparable to constant purchasing power. The relationship between per capita energy use and per capita income in equivalent purchasing power would have a much steeper slope than when incomes are based upon official exchange rates. Using the official exchange rate relationship for projecting future energy use when income growth is projected at constant prices would thus produce estimates which were too low.

Another way to see this is to examine the so-called income elasticity of demand for energy use. This is the measure used by economists to express the relationship between energy and income. It is equal to the growth rate over time of energy consumption divided by the growth rate over time of income. Per capita elasticities are usually higher than total elasticities, and when official exchange rates are used to convert country incomes, both elasticities tend to fall as per capita incomes increase.[2] At a per capita Gross Domestic Product level of, say, US$250 (in 1970 prices and exchange rates), the per capita elasticity of commercial energy use with respect to GDP might be about 1.5. With GDP expressed in purchasing power equivalent units, however, the elasticity would be closer to 1.7. The differences would be greater at higher per capita incomes and less for lower-income countries.[3]

For a given "real" (constant price) growth of GDP, use of a 1.5 instead of a 1.7 income elasticity would lead to a small underestimate

---

[2] Alan M. Strout, "Income Elastricities of Energy Consumption," preliminary draft, June 1967.

[3] _Ibid._, Tables 1 and 2.

of energy use. The relative underestimate would increase over time, and at a per capita GDP level of US$600, the difference might amount to one-fifth.

The second cause for bias in the usual chart relating energy use to per capita income is that energy prices cannot be taken into account. Past energy use relationships reflect low or declining energy prices. In a future period of high energy prices, would past relationships between energy demand and economics continue to be valid? This question has generated considerable controversy for countries at advanced development states. Some projection models for the United States, where much energy use is of a "luxury" nature, and hence presumably more readily influenced by relative price changes, suggest that future GDP growth might be accomplished with far less use of fuel and power than would be suggested by past relationships.[4]

At earlier stages of development, higher fuel prices should undoubtedly lead to some savings in energy use, especially in the longer run as more efficient machinery and processes can be introduced. Attempts to measure the relevant "price elasticities" are complicated by lack of data and by the fact that price changes in competing fuels should be looked at simultaneously. It is probable, however, that price elasticities in developing countries are much lower than in richer countries. One World Bank Study, for example found price elasticities

---

[4] Four of these studies are cited in Richard J. Barber Associates, <u>LDC Nuclear Power Prospects, 1975-1980: Commercial, Economic and Security Implications</u>, a report prepared for the Energy Research and Development Administration, ERDA-52, 1975, pp. I-29 to I-38.

for petroleum products in order of -.06 to -.11.[5] For developed countries, in contrast, other internal Bank studies have assumed an overall energy price elasticity of -.15.[6]

Thus, while energy projections based upon historical relationships may tend to overstate consumption in a time of higher prices, the bias may be rather small where developing countries are concerned.

The third reason for possible bias in historical relationships between energy and income has to do with a country's industrial structure. Cross-country relationships will reflect the distribution of industry among countries at a particular point in time. Relationships based on time series have built into them the past changes experienced by a particular country or group of countries. Neither situation may adequately reflect future changes in industrial structure.

Although a country's industrial structure has many different dimensions, the dimension most clearly related to energy use is the production of a rather small group of basic materials whose manufacture requires large amounts of energy, both directly and indirectly. The production of these materials may account for one-fourth of all energy used in the United States and over one-half of energy use in countries with a higher concentration of national product derived from steel,

---

[5] Adrian Lambertini, "Energy and Petroleum in Non-OPEC Developing Countries, 1974-1980," Bank Staff Working Paper No. 229, February, 1976, Annex II, pp. II-12. It should be noted that neither price elasticity shown in Annex II was statstically different from zero.

[6] Communication from John Foster, Economic Analysis and Projections Department, Development Policy Staff, IBRD. Much of the Bank's conclusions about developed countries are derived from a "Simrich" model described in J.W. Gunning, M. Osterrieth, and J. Waelbroech, "The Price of Energy and Potential Growth of Developed Countries, An Attempt at Quantification," European Economic Review, Vol. 7, No. 1 (January 1976).

other basic metals, paper, pulp, fertilizer, cement, etc.[7] When the production of a sample of these commodities is combined using energy weights, the resulting aggregate measure of "energy-intensive material" (EIM) is highly correlated with energy and electricity use at all levels of development.[8]

The developing countries are generally net importers of energy-intensive materials. With a few exceptions, principally Chile and Taiwan, they are historically low producers of energy-intensive materials when measured with respect to per capita income (see

---

[7] Alan M. Strout, "Energy and the Less Developed Countries: Needs for Additional Research," in Ronald G. Ridker, ed., Changing Resource Problems of the Fourth World (Washington: Resources for the Future, February 1976). Commodities included in the energy-intensive materials category were those which consume large quantities of energy under 1967 U.S. technological conditions and for which fairly homogeneous production statistics were available in physical units for a large number of countries. The commodity group is considerably narrower than "heavy industry" as usually defined, in that it does not include materials fabrication. In many countries, however, the production of these energy-intensive materials will be strongly correlated with the broader category, heavy industry.

[8] See Alan M. Strout, "Income Elasticities of Energy Consumption," for further details. For the statistical computations reported in the latter paper and in the current study, the energy-intensive materials group includes basic iron and steel, other primary metals (aluminum, copper, lead, inc, and tin), fertilizer production (measured by NPK content), hydraulic cement, pulp, paper, and paperboard. It would have been preferable to have also included refined petroleum production, magnesium, heavy chemicals other than fertilizer, and structural clay products (tiles and bricks).

Figure 1).[9] In this respect, the developing countries have evolved more in the direction of such developed countries as Denmark, New Zealand, and Switzerland. The major producers of energy-intensive materials with respect to GDP are Belgium,Luxemburg, Austria, Norway, Finland, Sweden, Canada, and Japan. Japan is by far the most important

---

[9] In Figures 1 and 2, a crude effort has been made to show per capita incomes in comparable purchasing power dollars. This has been done by fitting a regression to the ten GDP price indexes (USA=100) shown in Kravis, _et al._, Table 1.5, p. 9. (See note 1.) The fitted regression was then used to calculate crude GDP price indexes for all countries, and these price indexes were divided into observed per capita GDP (based on official exchange rates) to give an approximate adjustment for purchasing power comparability. Many different forms of this regression were investigated, some of which gave excellent statistical fits but led to unlikely results when extrapolated beyond the per capita GDP range covered by Kravis and his colleagues' ten-country sample. The relationship chosen for the current paper gave sensible results over a wide range of incomes although it was statistically poorer than several others. It included a population size variable, important when applying the results to small countries. (Small countries tend to be more "open" to foreign trade than do large countries, and both exports and imports are larger with respect to GDP. There thus tends to be less of a gap between the prices of domestically traded goods and services and foreign-traded goods in small countries. This in turn means that official-exchange-rate-based income will tend to be closer to constant-purchasing-power income in smaller countries.) The exact relationship was:

$$\ln YDGP = \underset{(1.85)}{.834} + \underset{(7.92)}{.477} \ln \frac{GDP}{POP} + 500 - \underset{(1.93)}{.071} \ln POP$$

$\bar{R}^2 = .871$, standard error of estimate = .134
(t-ratios are in parentheses)

where YGDP = GDP purchasing power index (USA=100) from Kravis _et al._, for 1970

GDP = Gross Domestic Product converted into U.S. dollars at official exchange rates, mean 1969/1970, from United Nations, _Monthly Bulletin of Statistics_, January 1975.

POP = mid-year population, 1970 (U.N. data)

ln = natural logarithm

The graphical results shown in Figures 1 and 2 are not greatly sensitive to the particular form chosen for the above regression.

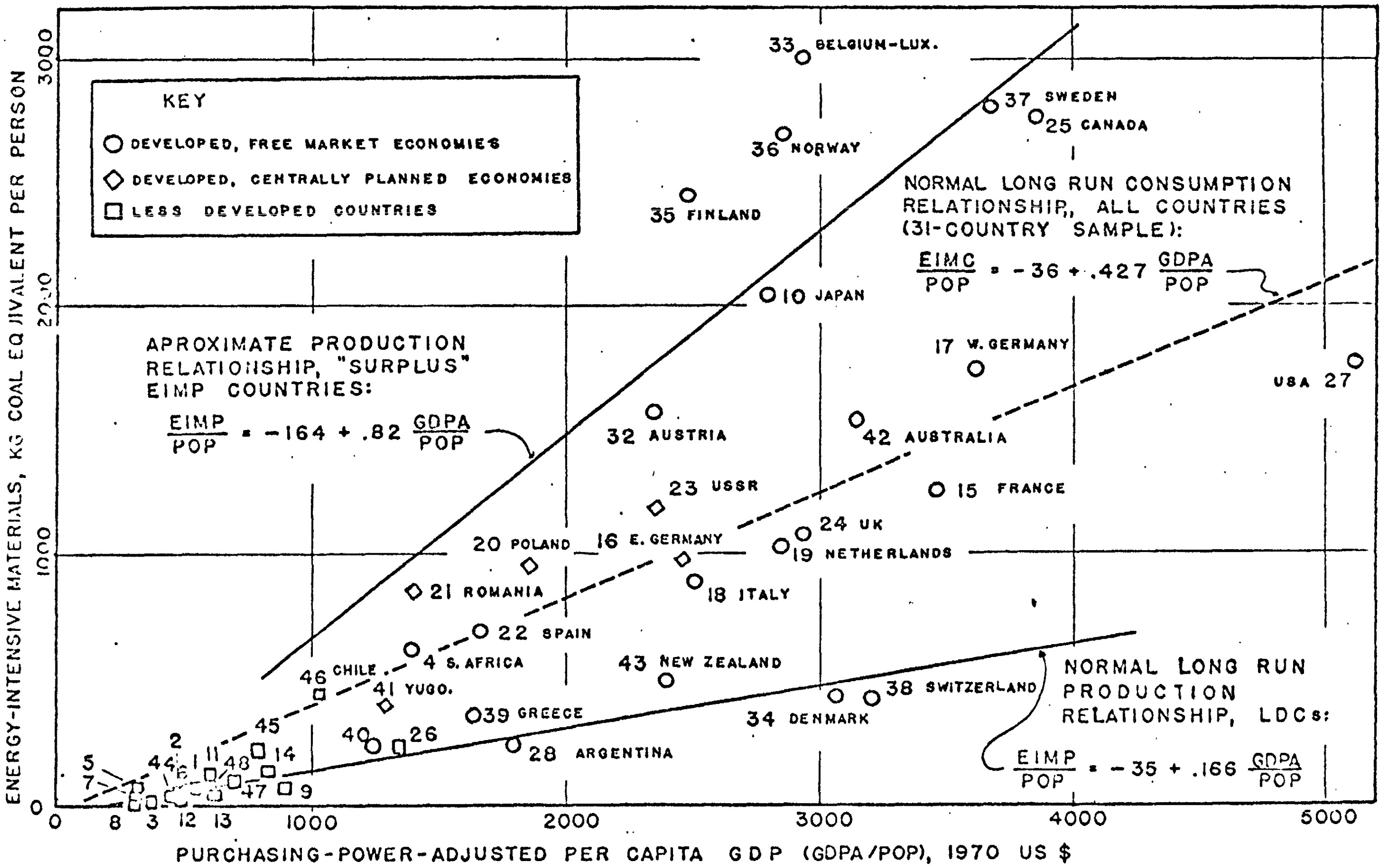

Figure 1. Per Capita Energy-Intensive Materials Production (EIMP/POP) vs Purchasing-Power-Adjusted Per Capita GDP (GDPA/POP), 48 Countries, Mean Value (Countries Included Are Listed Below)

Less Developed Countries:
1. Egypt
2. Morocco
3. Nigeria
5. Zaire
6. China, P.R.
7. India
8. Indonesia
9. Iran
11. Rep. of Korea
12. Pakistan + Bangladesh
13. Philippines
14. Turkey
26. Mexico
28. Argentina
29. Brazil
30. Colombia
31. Venezuela
44. Thailand
45. Taiwan
46. Chile
47. Peru
48. W. Malaysia

Developed, Centrally Planned Economies:
16. Germany, D.R.
20. Poland
21. Romania
23. U.S.S.R.
41. Yuogslavia

Developed, Free Market Economies:
4. S. Africa, Rep.
10. Japan
15. France
17. Germany, F.R.
18. Italy
19. Netherlands
22. Spain
24. Un. Kingdom
25. Canada
27. U.S.A.
32. Austria
33. Belgium/ Luxemburg
34. Denmark
35. Finland
36. Norway
37. Sweden
38. Switzerland
39. Greece
40. Portugal
42. Australia
43. New Zealand

quantitatively of this group and supplies much of the import requirements for deficit countries. Most other developed countries, including those of the socialist bloc, are in an intermediate position with regard to the production of energy-intensive materials. The dashed line in Figure 1 shows the production needed to satisfy domestic requirements assuming that production exactly equals consumption. The larger European countries lie relatively close to the self-sufficiency line. The United States lies below and quantitatively is the world's largest net importer of the particular commodities included in the EIM measure. Transitional developed countries such as Portugal and Greece lie closer to the historical LDC relationship between energy-intensive materials production and per capita income, while Spain, South Africa, and Yugoslavia are closer to the self-sufficiency line.

The self-sufficiency and LDC-production lines from Figure 1 are reproduced in Figure 2. The lines, derived from cross-country relationships observed in 1969/71, are juxtaposed with <u>time trends</u> for three groups of non-OPEC developing countries.[10] Each group shows a fairly linear

---

[10] The country grouping is the same as that used for World Bank Staff Working Paper No. 229. (Note 5.) The low-income non-OPEC countries had 1972 per capita incomes below $200, and the higher-income groups, above $374. The middle-income group fell between these two. Results for the low income group are dominated by India; the higher income group, by Latin American countries. 1969/71 mean data for the three groups, taken from the current study, are:

| | Low Income | Middle Income | High Income |
|---|---|---|---|
| Total population, $10^6$ (POP) | 921 | 226 | 281 |
| Per Capita GDP, 1970 $US | | | |
| Official exchange rate | 101 | 240 | 574 |
| Converted using purchasing Power indexes (see note 9) | 299 | 544 | 1151 |
| Per capita prod. energy-intensive mtls, kg coal-equiv. (EIMP/POP) | 25 | 50 | 174 |

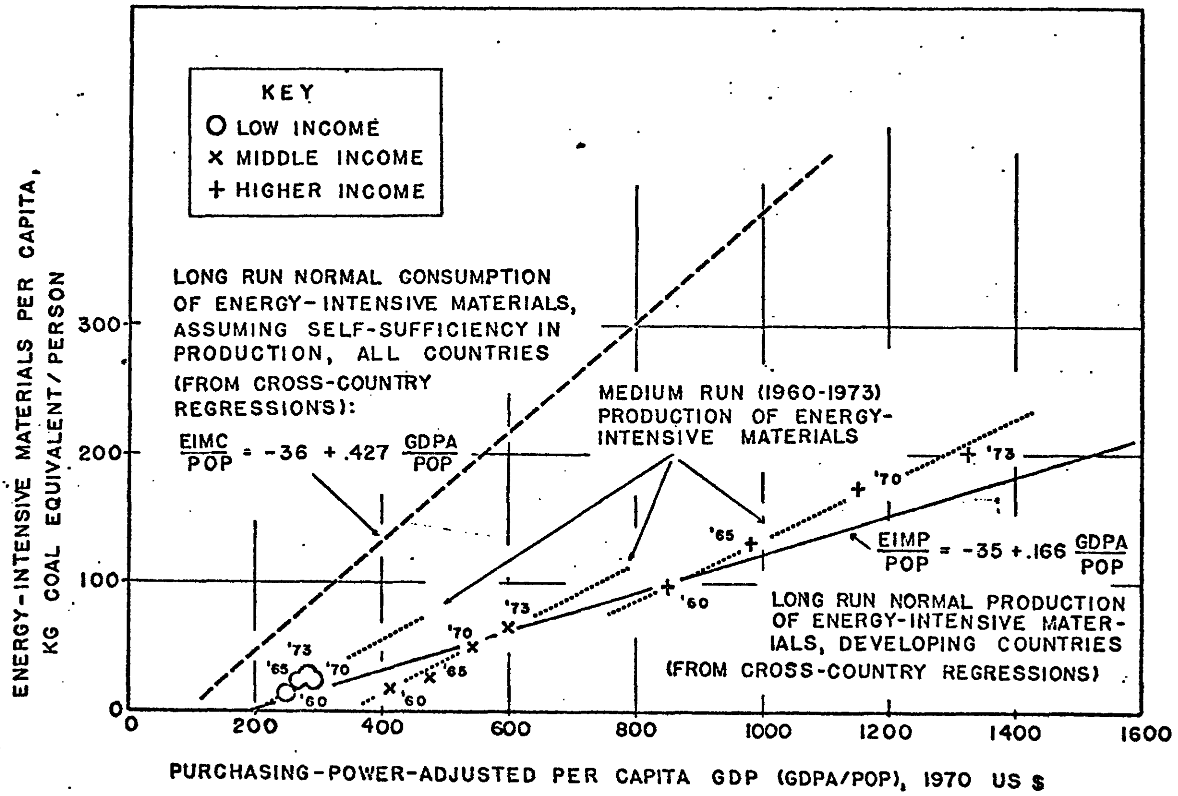

Figure 2. Per Capita Production Of Energy-Intensive Materials vs. Purchasing-Power-Adjusted Per Capita GDP, Non-OPEC Developing Countries, 1960, 1965, 1970, and 1973

growth over time (in relationship to per capita GDP). The slopes all appear to be steeper than the long-run production curve for the same countries (taken from cross-country results for 1969/71), but less steep than the "self-sufficiency" long-run relationship for all countries. No subgroup of developing countries, including the "higher income" group containing Taiwan and Chile shows production increasing at anywhere near the rate which in the past must have characterized countries such as Austria, South Africa, or Australia.

The implication of Figure 2 is that energy-consumption projections for developing countries, derived from historical relationships between energy use and income, will be more accurate if future change in industrial structure (represented by the production of energy-intensive materials) conforms to past trends. Past medium-run trends (1960-1973) suggest that EIM production (EIMP in the figures) has been increasing faster for <u>each</u> group of developing countries than would have been suggested by the longer-run, cross-country-derived relationship. This medium term trend, however, would never bring the countries to "self-sufficiency" in EIM production, assuming the normal, all-country relationship between energy-intensive materials consumption (EIMC in the figures) and per capita GDP that has existed historically.

It may be assumed that some developing countries in the future, particularly those endowed with relatively plentiful energy resources, will attempt to follow the heavy industry development strategy of South Africa, Spain, and many of the socialist bloc countries. It is significant, however, that during the 1960-1973 period of relatively inexpensive energy prices, the non-OPEC developing countries as a whole made little progress in this direction. If anything, the gap between normal consumption and actual production of energy-intensive materials has appeared to widen. It is possible that in the future the developing countries as a group may have even less success in overcoming the historical advantage of today's industrialized, net exporters of energy-intensive materials.

Since total commercial energy (and electricity) consumption is strongly influenced by the production of energy-intensive materials, it thus appears likely that the non-energy-rich developing countries will not experience income elasticities of demand for energy in the future that are as high as those recorded by today's more industrialized countries. There is even some question as to whether the energy/GDP relationship for these countries may not in the future fall below the historical trend for the developing countries themselves.

Finally, the fourth reason for possible bias in the historical relationship between per capita energy consumption and per capita income lies in the fact that in the past not all fuels have been burned with equal efficiency in use. Coal-fired equipment, for example, has generally been less efficient than that using oil or natural gas. Electricity-using machinery and equipment usually convert a high portion of the electric energy into useful work or heat, but there are large, prior energy losses in the production and distribution of electric energy.

When energy consumption in a country is added up to produce a grand total, the various primary fuels are typically combined using their direct calorific heat values. No allowance is thus made for differing efficiencies in actual use. It would, in fact, be difficult to arrive at such estimates of country-wide average efficiencies. Using statistical inference based on aggregate data, however, it appears that a country's total per capita energy use is positively related to the portion of the total consumed in the form of coal.

## Future Energy and Electricity Requirements of the Developing Countries

The intent of the previous section was to confirm the oft-cited strong association between economic growth and energy consumption, but to raise doubts about the exact nature of the relationship. Cross-country statistical relationships are suspect unless country incomes are made comparable in terms of purchasing power. Future price changes will have some effect upon demand, but the magnitude of the effect is very difficult to assess and may be relatively minor. Aside from the general growth rate in per capita income, the largest future effect on energy use will probably come from any changes which may occur in the production of energy-intensive materials. In the recent past, for three groups of non-OPEC developing countries, the per capita production of energy-intensive materials has borne a roughly linear relationship to the growth of purchasing-power-adjusted per capita GDP. (See Figure 2.) In the future, this past relationship is likely to continue even though it will imply a widening gap between aggregate production and "normal" consumption of energy-intensive materials.

The linear relationship between per capita GDP and energy-intensive materials production is paralleled for these same three groups of developing countries by approximately linear relationships between per capita income and energy use. These are shown in the top portion of Figure 3. "Commercial" energy in this case follows the definition of the United Nations in excluding fuelwood, dung, and all vegetal wastes. The production of primary electrical energy (hydro, geothermal, nuclear) as well as net

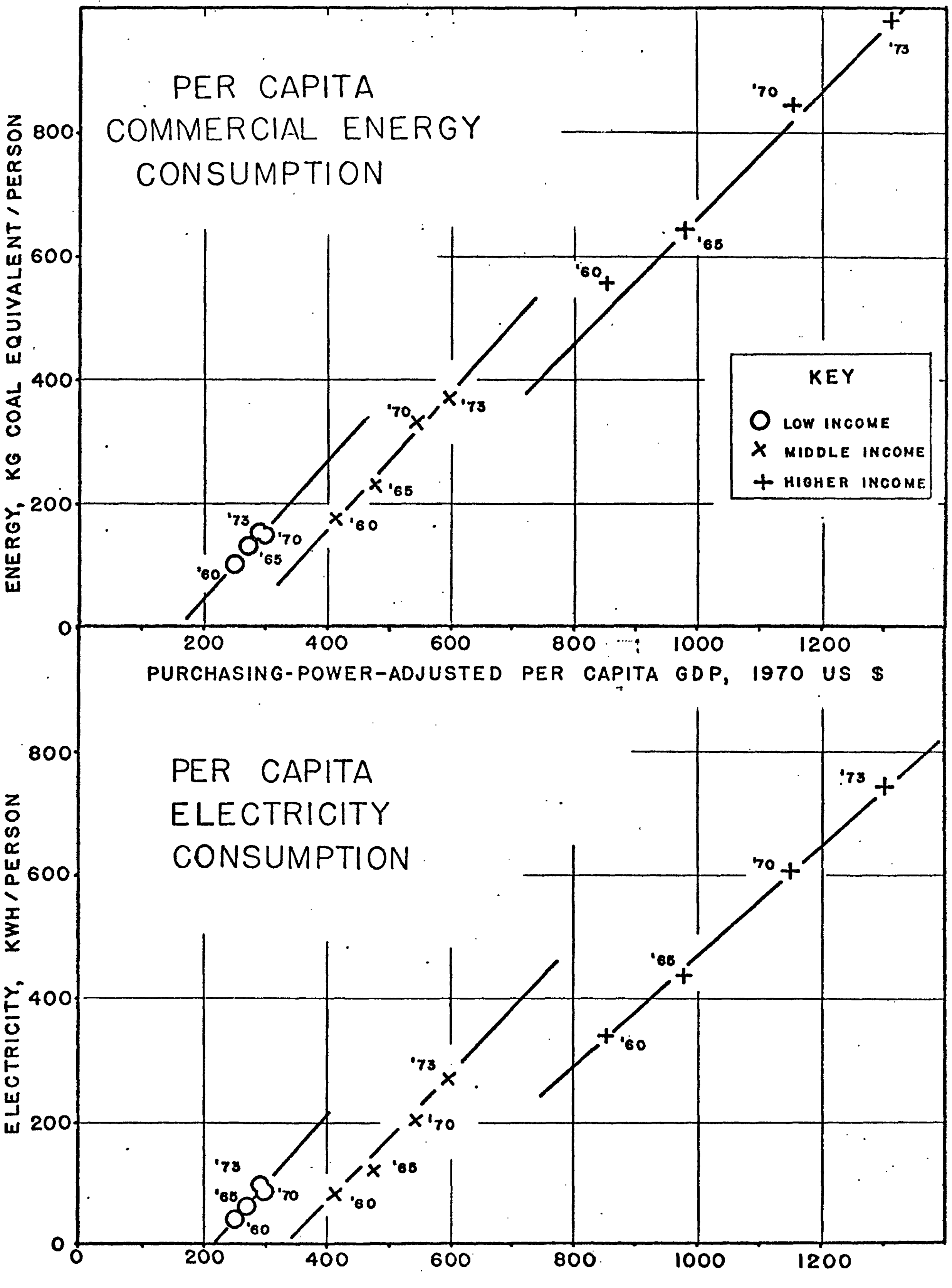

Figure 3. Per Capita Energy Consumption vs. Purchasing-Power-Adjusted Per Capita GDP, Non-OPEC Developing Countries, 1960, 1965, 1970 and 1973

It is suggested that the relationships shown in Figure 3 may prove acceptable guides to future energy use in these three groups of non-OPEC countries, assuming the continuation of past trends in energy-intensive materials production for each country group. The effect of higher current energy price levels than existed over most of the historical period would be to depress the lines. This would also be the effect of any failure to maintain past rates of energy-intensive materials production. (Some countries, of course, will always differ from the averages shown, and the Figure 3 curves can represent no more than a central tendency for each subgroup of countries.)

For projection purposes, assumptions are needed about future growth rates of population and real income. These are given for each country subgroup in Table 1, along with historical rates during 1965-1973. Population growth rates for each subgroup have been assumed to decrease slightly over the next 25 years with somewhat greater decreases occurring in the higher income group. The 1975-1980 real (purchasing power-adjusted) GDP growth rates are those used in a recent World Bank study and are more conservative than recent growth rate targets for many of these same countries.[12] The 4.5 percent per year assumption for the low-income group is the only case where future growth is at a higher rate than that of the recent past. (For this group of countries, the 1960-1970 average was 4.0 percent per year, and this rate fell to 1.8 percent annually between 1970 and 1974).

For the middle- and higher-income countries, GDP growth during 1980-2000 has been projected at the 1973-1980 rate of 5.5 percent per year. That for the lower-income group is assumed to increase slightly to 5.0 percent per year.

---

[12] World Bank Staff Working Paper No. 229, op. cit., p. 2, footnote 1.

Table 1

Growth Rate Assumptions for Energy Consumption

Projections, 1973-2000, Non-OPEC Developing Countries

| Country Subgroup | Variable | Annual Growth Rate, %<br>1965-73 Actual | 1973-90 Assumed | 1980-2000 Assumed |
|---|---|---|---|---|
| Low income | Population | 2.51 | 2.40 | 2.25 |
| | Real GDP | 3.41 | 4.5 | 5.0 |
| Middle income | Population | 2.75 | 2.65 | 2.50 |
| | Real GDP | 5.62 | 5.5 | 5.5 |
| Higher income | Population | 2.76 | 2.60 | 2.40 |
| | Real GDP | 6.52 | 5.5 | 5.5 |

Source: 1965-73 population growth based on U.N. country estimates, Monthly Bulletin of Statistics, Jan. 1975, supplemented in a few cases by World Bank Atlas, 1975. 1965-73 GDP growth rates from World Bank Staff Working Paper No. 229, *op. cit.*, Table 2. For discussion of assumptions, see text.

Energy and electricity projections based upon the Table 1 assumptions and the Figure 3 graphical relationships are shown in Table 2. They have been plotted against time in Figures 4, 5, and 6. Several observations may be made about these results.

First, the 1973-1980 growth rate projected for total commercial energy is considerably higher than that currently employed by the World Bank. From Table 2, the projected growth rate for the three groups of non-OPEC countries are seen to average 6.7 percent per year. In the World Bank Staff Working Paper cited several times above and whose estimates are the basis for more recent internal Bank memoranda, the comparable rate was 4.5 percent under the assumption of no further change in real crude oil prices or 4.9 percent per year if a 29 percent drop in crude oil prices is assumed.[13] In terms of the familiar aggregate (as opposed to per capita) income elasticity concept, this current study implies an average elasticity of 1.30 for the non-OPEC countries. That implied by the Bank study ranges from .88 to .95. The Bank projections led to the rather sanguine conclusion that "all the non-OPEC developing countries together have enough economically recoverable energy resources to reduce their dependence on energy imports from other groups of countries from about 30% in 1974 to between 12% and 5% in 1980."[14] The probable explanation for the difference between the two sets of results is that the Bank projections gave a greater weight to the early 1970's price changes than would seem justified by the low price elasticities found by the same study. Exact comparison between the two studies is made difficult, however, by energy data discrepancies referred to in Note 11.

---

[13] *Ibid.*, Table 2, p. 4.

[14] *Ibid.*, abstract, title page.

## Table 2

## Projections of Population, Gross Domestic Product, Commercial Energy and Electricity Consumption, Non-OPEC Developing Countries, 1973-2000

| Variable | Units | Actual | Projected[a] | | |
|---|---|---|---|---|---|
| | | 1973 | 1980 | 1990 | 2000 |
| **Low income countries** | | | | | |
| Population | $10^6$ | 996.0 | 1176 | 1466 | 1835 |
| GDP, 1960 US$ | $10^9$ | 98.32 | | | |
| GDP adjusted to common purchasing power, 1970 US$[2] (GDP-Adj.) | $10^9$ | 298.8 | 406.6 | 662.4 | 1078.9 |
| GDP per capita | 1970 US$ | 101.4[c] | | | |
| GDP-Adj. per capita | 1970 US$ | 300 | 346 | 452 | 588 |
| Commercial energy, coal equivalent | MT x $10^6$ | 151.66 | 239.90 | 472.05 | 871.62 |
| Electricity | Kwh x $10^9$ | 96.60 | 171.70 | 378.23 | 778.04 |
| Per capita: | | | | | |
| Commercial energy, coal equivalent | kg | 152 | 204 | 322 | 475 |
| Electricity | Kwh | 97 | 146 | 258 | 424 |
| **Middle income countries** | | | | | |
| Population | $10^6$ | 244.0 | 293 | 375 | 480 |
| GDP, 1970 US$ | $10^9$ | 64.25 | | | |
| GDP-Adj.[b], 1970 US$ | $10^9$ | 124.4 | 211.5 | 361.4 | 617.2 |
| GDP per capita | 1970 US$ | 263 | | | |
| GDP-Adj. per capita | 1970 US$ | 596 | 722 | 964 | 1286 |
| Commercial energy, coal equivalent | MT x $10^6$ | 90.66 | 150.60 | 294.38 | 549.60 |
| Electricity | Kwh x $10^9$ | 66.07 | 118.08 | 246.48 | 477.60 |
| Per capita: | | | | | |
| Commercial energy, coal equivalent | kg | 372 | 514 | 785 | 1145 |
| Electricity | Kwh | 271 | 403 | 657 | 995 |

(CONTINUED)

Table 2 (CONTINUED)

| | | | | | |
|---|---|---|---|---|---|
| Higher income countries | | | | | |
| Population | $10^6$ | 305.4 | 366 | 463 | 587 |
| GDP, 1970 US$ | $10^9$ | 199.15 | | | |
| GDP-Adj.[b], 1970 US$ | $10^9$ | 399.2 | 580.6 | 991.8 | 1694.2 |
| GDP per capita | 1970 US$ | 652 | | | |
| GDP-Adj. per capita | 1970 US$ | 1307 | 1586 | 2142 | 2886 |
| Commercial energy, coal equivalent | MT x $10^6$ | 299.60 | 463.36 | 848.68 | 1521.50 |
| Electricity | Kwh x $10^9$ | 228.08 | 365.27 | 694.04 | 1272.62 |
| Per capita: | | | | | |
| Commercial energy, coal equivalent | kg | 981 | 1266 | 1833 | 2592 |
| Electricity | Kwh | 747 | 998 | 1499 | 2168 |

---

[a] Using the initial figures shown in the 1973 column, the growth rate assumptions from Table 1, and the following approximate relationships from Figure 3:

| | Per Capital Commercial Energy | | Per Capita Electricity | |
|---|---|---|---|---|
| | Intercept | Per Capita GDP-Adj. coef. | Intercept | Per Capita GDP-Adj. coef |
| Low income | -185 | 1.12 | -248 | 1.15 |
| Middle income | -295 | 1.12 | -355 | 1.05 |
| Higher income | -352 | 1.02 | -429 | .90 |

[b] See Note 9 for the equation used to calculate a purchasing power price index for 1969/71. Since the 1973-2000 GDP projections were in "real" prices of 1970, this index was then used to adjust the real GDP estimate for each of these latter years.

[c] Actual 1973 GDP per capita was reported at $98.7. This was below the 1970 average of $101.2, and the 1973 figure shown has consequently been adjusted upward to be consistent with actual energy use reported for 1973.

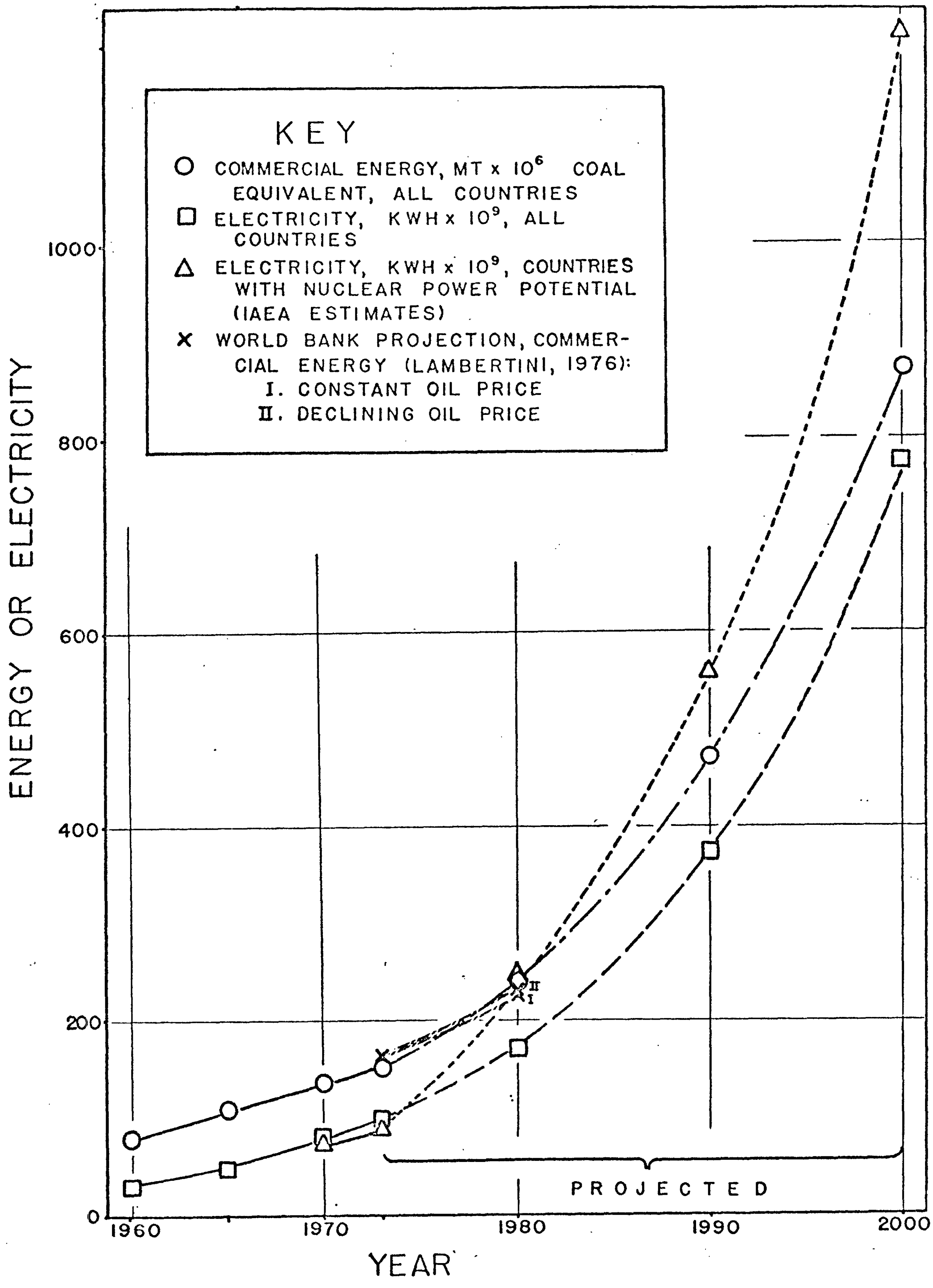

Figure 4. Projected Growth of Commercial Energy and of Electricity Consumption, 1973-2000, Low Income Developing Countries (Non-OPEC)

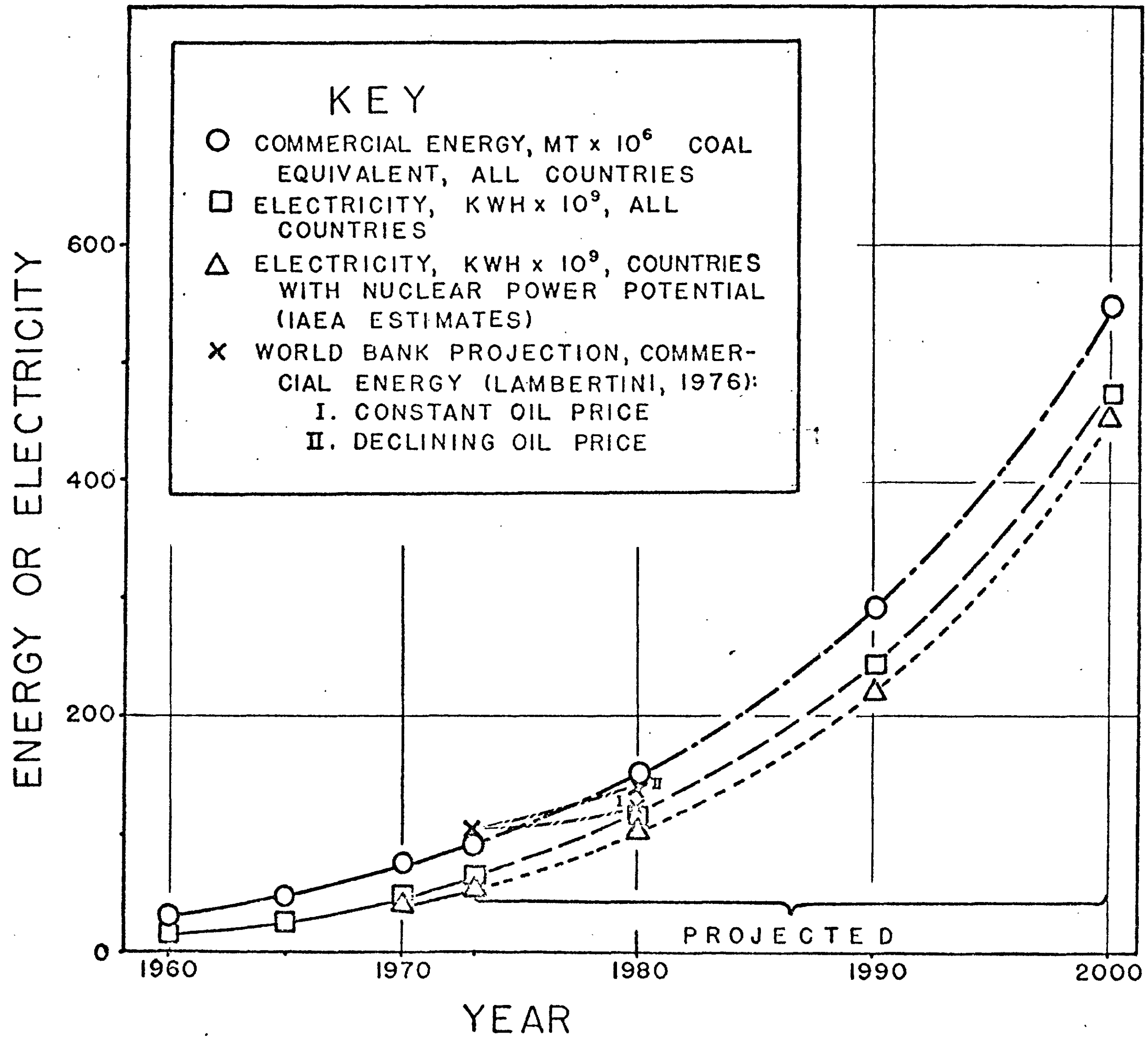

Figure 5. Projected Growth of Commercial Energy and of Electricity Consumption, 1973-2000, Middle Income Developing Countries (Non-POEC)

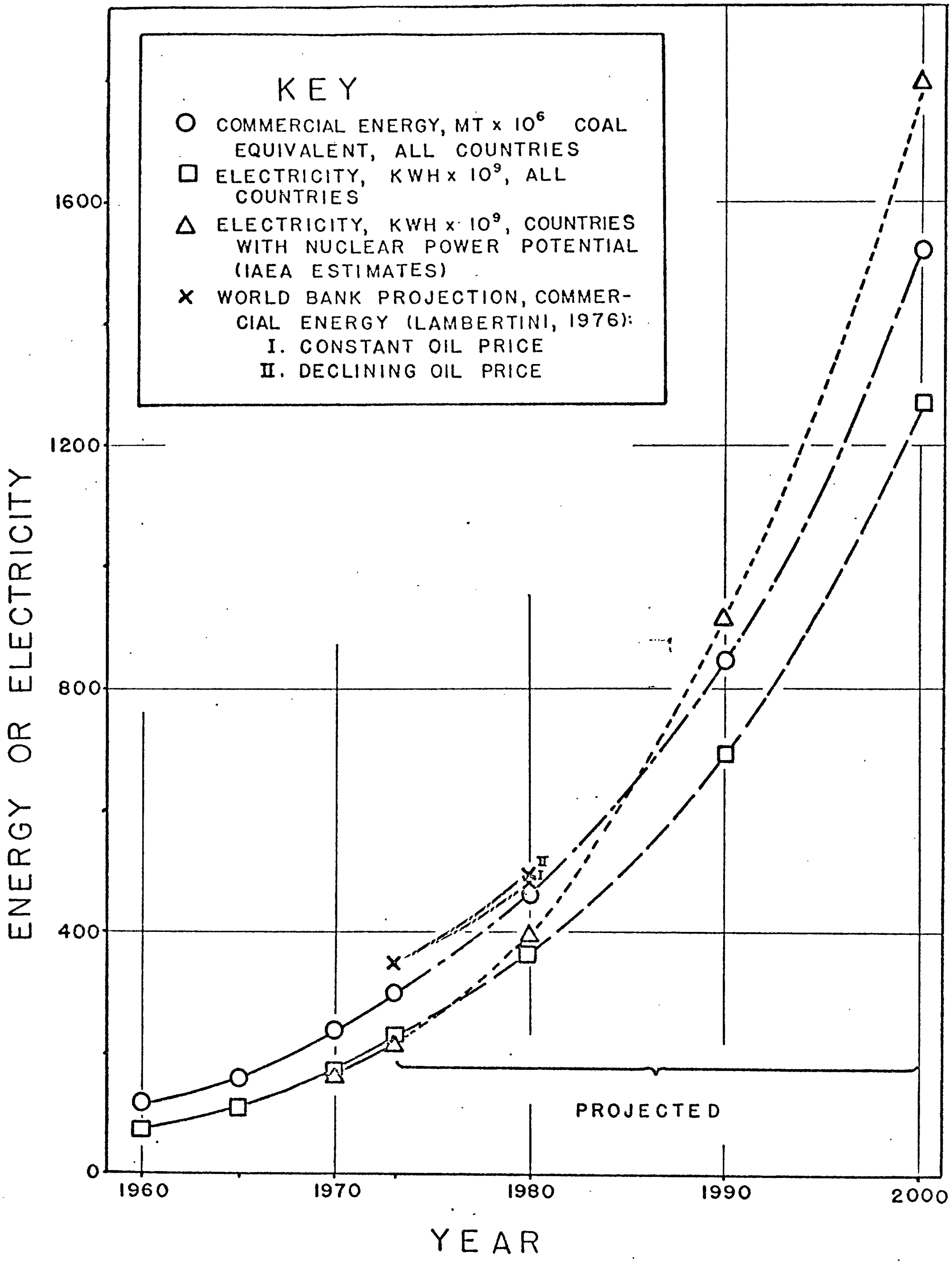

Figure 6. Projected Growth of Commercial Energy and of Electricity consumption, 1973-2000, Higher Income Developing Countries (Non-OPEC)

The second observation is that the electricity projections shown in Table 2 for the low- and higher-income groups are much lower than those made in 1974 by the International Atomic Energy Agency.[15] The IAEA projections are important because they form the basis for that Agency's projections of the future market for nuclear power in the developing countries. The projections are confined to a relatively small group of 35 non-OPEC developing countries identified by the IAEA as being potential prorducers of nuclear power. (This more limited group nevertheless accounts for almost all electric power consumption in the non-OPEC developing countries.) The two sets of projections are compared in greater detail in Table 3.

The differences for the low-income group are largely accounted for by one country, India. The IAEA projects India's electric power generation to grow at 13.3 percent per year between 1970 and 1980 and by 8.2 percent annually in the following decade. The IAEA does not report the GDP growth rate assumption on which this estimate is based, and the projection is probably too high. According to the "demand path" chart of electricity use which the IAEA presumably used for country projections where special studies had not been made, a 13.3 percent electricity growth rate for India

---

[15] International Atomic Energy Agency, Market Survey for Nuclear Power in Developing Countries, 1974 edition (Vienna: IAEA, 1974, Table IX.)

## Table 3

## Alternative Projections of Energy Consumption and Production, 1970-2000

| | Actual | | Projected | | |
|---|---|---|---|---|---|
| | 1960 | 1970 | 1980 | 1990 | 2000 |
| | | (kilowatt hours x $10^9$) | | | |
| Non-OPEC Developing Countries | | | | | |
| Low income | | | | | |
| All countries, consumption | 27.9 | 80.8 | 171.7 | 378.2 | 778.0 |
| 5 countries with nuclear potential | | | | | |
| Consumption | 23.0 | 70.5 | | | |
| Generation (IAEA) | - | 70.2 | 245.5 | 559.6 | 1214.7 |
| (Of which India) | | (60.0) | (21.0) | (462.0) | (1000.0) |
| Middle income | | | | | |
| All countries, consumption | 13.9 | 46.3 | 118.1 | 246.4 | 447.6 |
| 10 countries with nuclear potential | | | | | |
| Consumption | 11.1 | 38.8 | | | |
| Generation (IAEA) | | 35.0 | 104.2 | 222.4 | 451.9 |
| Higher income | | | | | |
| All countries, consumption | 73.9 | 171.6 | 365.3 | 694.0 | 1272.6 |
| 20 countries with nuclear potential | | | | | |
| Consumption | 70.8 | 163.1 | | | |
| Generation (IAEA) | - | 153.1 | 395.9 | 914.1 | 1794.9 |
| OPEC Countries | | | | | |
| All 13 countries | 11.1 | 33.7 | na | na | na |
| 9 countries with nuclear potential | | | | | |
| Consumption | 11.0 | 32.9 | | | |
| Generation (IAEA) | - | 30.2 | 96.8 | 233.6 | 451.2 |

Source: 1960-1970 consumption from U.N. Stat. Papers, Series J-19.
1970-2000 projected consumption from Table 2.
1970 actual and 1980-2000 projected generation from IAEA, *Market Survey for Nuclear Power*..., 1971 ed., Tables VIII, IX.

would seem to correspond to a 9.5 percent annual growth of total GDP.[16] This is considerably greater than most observers believe possible for India during the remainder of this decade.

The differences for the higher-income group probably arise from two causes: higher GDP growth rate and slightly higher-income elasticities of demand assumed for the IAEA projections. The IAEA may have projected GDP growth for this group to be as great as 7 percent per year between 1970 and 1980 and perhaps 6.5 percent in the decade thereafter.[17] These rates contrast with the 5.5 percent growth assumed for Tables 2 and 3.

---

[16] J.A. Lane, "Long-Range Forecasting of the Demand for Electrical Energy," Appendix D to International Atomic Energy Agency, <u>Nuclear Power Planning Study for Bangladesh</u> (Vienna: IAEA, 1975), p. 185. Lane's demand-path chart is based upon the "Aoki method" of electricity demand forecasting described in the 1973 IAEA nuclear power market survey report (<u>Market Survey for Nuclear Power in Developing Countries: General Report</u>, Vienna, September 1973). To calculate an implicit GDP growth rate for India, 1970 data for India from IAEA sources (<u>Market Survey</u>..., 1974 ed., Table VIII, cited in Note 15) were used and the assumption was made that 1970-1980 population growth continued at the 1963-1970 rate of 2.1 percent per year.

[17] For five of the higher-income countries, IAEA growth rate assumptions are available in <u>Market Survey for Nuclear Power</u>..., General Report, p. 10. Other GDP growth rates were taken from Fremont Felix, <u>World Markets of Tomorrow</u> (London: Harper and Row, 1972), Part Two. This latter source was referred to by J.A. Lane in the article cited in Note 16 and seems to have been the basis for IAEA GDP projections when other sources were not available.

The income elasticity differences arise from a more complicated set of reasons. The electricity demand model underlying the IAEA projections is based essentially on cross-country consumption and income data from the 1960's.[18] It is thus subject to all of the biases described in the earlier section on the relationship between energy use and economic growth. Most importantly, the purchasing power bias in GDP conversions will lead to an understatement of electricity needs when projections are based on assumed growth of real income. On the other hand, the worldwide "normal" or "universal" relationship assumes a certain pattern of industrial structure changes (particularly the production of energy-intensive materials) as economic growth proceeds. If, as seems likely, the developing countries are not following the historical pattern, then electricity consumption will be overestimated.

A further complication has been introduced in the current instance by the decisions to use the linear relationships of Figure 3 for projection purposes. A logarithmic relationship would have fitted the 1960-1973 time paths equally as well and would have led to much higher estimates of future

---

[18] The model is associated with the name of H. Aoki and is briefly described in H. Aoki, "Long-Range Forecasting of the Demand for Electrical Energy," Appendix F to International Atomic Energy Agency, Market Survey for Nuclear Power in Developing Countries: General Report, op. cit. See also H. Aoki, New Method of Long-Range or Very Long-Range Demand Forecast of Energy, Including Electricity, Viewed from a Worldwide Standpoint (Tokyo: Electric Power Development Co., Ltd., 1974). A more up-to-date description of the current IAEA procedure is given in J.A. Lane, "Long-Range Forecasting...," cited in Note 16. While the electricity/GDP relationship is basically that obtained from cross-country analysis for the year 1968, countries whose initial positions lie above or below the "normal" or "universal" curve are assumed to move closer to the norm as time progresses.

electricity consumption. Logarithmic projection curves were not used, however, since the slopes for the three country groupings differed strongly and raised serious questions about how the slopes should be projected to change during the course of future economic growth. This problem was largely avoided when using non-logarithmic curves, since, as can be seen from Figure 3, the slopes of the three country groupings are quite similar.[19]

The net effect of these various differences for the higher-income countries was to produce slightly higher income elasticities of demand for electricity, as already noted, and thus to increase the gap between the IAEA projection and those derived in Table 2. For the middle-income countries, however, the various biases virtually canceled one another out, and the projections summarized in Table 3 are quite consistent with each other.

The third and most important observation about the projections of Table 2 is that, in spite of the relatively conservative assumptions employed, energy and electricity consumption are seen to increase enormously over the remainder of this century. Between 1973 and 2000, population in the non-OPEC developing countries is assumed to not quite double, and total Gross Domestic Product to increase by a factor of 4. Commercial energy,

---

[19] The logarithmic slopes for the three country groups may be compared with those from Figure 3 as follows:

| Medium-run, 1960-73 | Mean per capita GDP, 1973 | Linear slope, Fig. 3 | Equivalent log-linear slope |
|---|---|---|---|
| Low income | $101 | 1.15 | 6.75 |
| Middle income | 263 | 1.05 | 3.68 |
| Higher income | 652 | .90 | 1.88 |
| Long-run, cross country | | | 1.39 |

however, would increase by a factor of 5.4, and electricity by 6.5.

## Alternative Sources of Energy Supply

Where will the non-OPEC developing countries obtain the large amounts of energy needed for the relatively modest economic growth projected in Table 2? And, in particular, how important a role might be anticipated for nuclear power?

To put this issue in perspective, it should be noted that the energy requirements of the developing countries come to only a fraction of global demand. The developing country share of total world consumption was about 6 percent in 1960 and 9 percent in 1974.[20] By 1980, the share might reach 13 percent, rising to perhaps 23 percent by the year 2000.[21] Secondly, if the large, "recoverable" world reserves of coal can be fully used, the world

---

[20] United Nations, World Energy Supplies, 1950-1964, op. cit., Table 2. "Developing country" as used in the present study conforms to the World Bank definition and differs from that of the U.N. by excluding Turkey, Cuba, Greenland, Puerto Rico, and the Panama Canal Zone, and by including Israel.

[21] Harry Perry, "Energy Demand - World Less the United States," (draft of 4/6/76), in Ronald G. Ridker, ed., ______________________________ (Resources for the Future: forthcoming). The Perry estimates were derived through rather crude correlations between past GNP growth and energy consumption but nevertheless indicate the rough orders of magnitude for future demand. Consumption by developing countries is projected to increase at the rate of 6.5 percent annually between 1980 and 2000, a result remarkably close to the 6.4 percent rate projected for the non-OPEC countries in Table 2. (Both studies assumed weighted average LDC growth rates of GDP of about 5.3 - 5.4 percent per year.) Consumption for the non-developing portion of the world, including China, was projected to increase at the rate of only 2.9 percent annually, thus resulting in a further increase of the LDC relative share.

appears to have adequate supplies of conventional, nonrenewable energy resources for at least another fifty years.[22] Thus, the choice of a particular fuel, including the nuclear fuels, will be largely determined by economic and perhaps environmental or strategic considerations. Third, unless the historical use of electricity changes far more rapidly than now anticipated, or unless the use of nuclear power for industrial process heat is resurrected as a desirable option, nuclear power could at most provide one-third of energy needs in the non-OPEC developing countries in the year 2000. (This assumes that all the electricity shown in Table 2 is nuclear-generated at an average thermal efficiency of about 32 percent.) Thus, conventional fuel sources are likely to play an important role in developing countries throughout the foreseeable future.

In the near term, at least, prospects appear good that the non-OPEC countries can, as a group, provide most of their energy needs from indigenous sources. The World Bank study already referred to estimates that this group of countries increased its production of fuel and primary energy at the rate of almost 7 percent per year between 1965 and 1974. The growth rate to 1980 could be accelerated to 9.6 percent annually, according to the same study, at only a relatively minor increase in the share of GNP used for

---

[22] Harry Perry, "World Energy Resources and Reserves and Estimated Production Rates," (draft of 2/18/76), in Ronald J. Ridker, ed., op. cit. "Proved recoverable" nonrenewable energy resources are estimated at 32.8 Btu x $10^{18}$ as of 1972. The demand forecasts cited in Note 21 suggest that these recoverable reserves (of which 73 percent are coal and only 4 percent are uranium) would be just about fully exhausted by 2025 if no use at all were made of renewable energy resources. Renewable energy sources, particularly hydropower, would, of course, be used, and Perry also estimates that an additional 200 Btu x $10^{18}$ of energy resources will be discovered in the earth's crust and will be recoverable at prices prevailing in the future.

domestic fuel and power investment.[23] Investment in absolute terms might have to increase by a large amount, from an annual average of $4.2 billion (1973 prices) during 1968 to $7.1 billion annually (also in 1973 prices) during 1974-1980. As a percentage of GDP, however, the increase would only be from 1.2 percent in the first period to 1.4 percent in the latter. (The relative increase for the group of low-income non-OPEC countries, however, would be greater: from 0.6 percent of GDP in 1968-1973 to 1.3 percent in 1974-1980.)

It appears, furthermore, that economically recoverable, currently known energy resources in the non-OPEC countries would be sufficient to supply this group of countries with their energy needs until almost the end of the century.[24] Since the prospects for additional discoveries of hydrocarbons

---

[23] Adrian Lambertini, "Energy and Petroleum in Non-OPEC Developing Countires," World Bank Staff Working Paper No. 229, February 1976, Tables 1 and 5. The consumption estimates in the Lambertini report appear to start from a higher base than would seem indicated by the latest United Nations estimates (see Note 11, above) and to grow at slower rates than projected in the present study. Total 1980 demand as estimated by Lambertini, however, is only slightly less than that shown in Table 2 of this study. For the non-OPEC developing countries as a whole, assuming no relative change in future oil prices, the difference between 1980 supply and demand as given by Lambertini would be seven percent. The 1980 difference using the Lambertini supply forecast and the demand projections from the present study would be nine percent.

[24] Ibid., p. 6, Table 3. The estimates shown are for "medium term" reserves. For oil and natural gas (one-fourth of the total), they are estimates of amounts economically recoverable at current prices and costs, for coal (65% of the total) and nuclear power (6%), they are the "measured or reasonably assured fraction of resources which could be economically exploited in the coming 5 years," while for hydropower (2%), all estimated reserves have been included. The total of 22,320 million metric tons of oil equivalent or 930 Btu x $10^{15}$ compares with 1973-2000 cumulative production of 1056 Btu x $10^{15}$, based upon the projections of Table 2.

appear to be very good, this reinforces the conclusion of this section that absolute shortages of energy should not be a general problem in the foreseeable future. There may be some further increases in energy prices (although even that is a debatable point), and individual countries may continue to have difficulties in earning sufficient foreign exchange to pay for imported energy when domestic sources are deficient. Choice of particular fuels by individual countries in the future should continue to be determined by the same factors which have operated in the past: relative costs, ability to earn foreign exchange, and strategic considerations.

## Economics of Electric Power Generation and Distribution

The uncertainties about nuclear generating costs and about future fossil fuel prices are as great for developing countries as they are for the rest of the world. These uncertainties translate into a high degree of risk when trying to choose a least-cost solution to an LDC's future power system expansion. The International Atomic Energy Agency has borrowed extensively from the AEC and has developed careful and sophisticated techniques for converting capital costs to LDC conditions and for planning future power system growth.[25] The particular assumptions chosen by the IAEA lead to the clear conclusion that nuclear power plants will provide the least cost alternative for almost all future additions to LDC generating capacity.[26]

---

[25] See the series of 14 country studies summarized in International Atomic Energy Agency, Market Survey for Nuclear Power in Developing Countries: (Vienna: IAEA, September 1973). The cost-calculating procedures are described in lengthy appendices included with each of the reports and with the General Report.

[26] In a follow-up report made after the full impact of the oil price increases had been felt, the IAEA examined a group of 50 countries outside of the Soviet bloc, mostly LDC's, but including such transitional countries as Spain, Yugoslavia, Greece, Turkey, and Israel. Between 1980 and 2000, the IAEA estimated that nuclear power would account for 75% of all expansions in generating capacity while 20% would be hydro. Only 5% would consist of fossil fuel plants. (See also Table 5, below.) The 50-country sample includes almost all electrical generating capacity in the developing world. See IAEA, Market Survey..., 1974 Edition, Table XIII.

The IAEA assumptions and procedures have, in turn, been carefully scrutinized in a recent study by Richard J. Barber Associated (hereafter to be abbreviated as RJBA).[27] The latter study, which includes a detailed and generally excellent review and discussion of the many and various generating cost elements, believes that the IAEA assumptions lead to the "most favorable" scenario for nuclear power expansion. The RJBA study proposes a more conservative, "medium" set of assumptions and a still more conservative scenario designed to be unfavorable to nuclear power. (All three scenarios deal only with economic issues vis-à-vis alternative production of electricity by coal or oil.)

The most important differences among the various assumptions concern the cost and utilization of capital. RJBA believes that initial capital costs will be more expensive in developing countries than in the United States, rather than less expensive. The differences apply about equally to fossil plant costs, however, and do not greatly affect the choice between nuclear and fossil. A more important assumption is that of the discount rate for converting total capital investment to an equivalent annual cost. The 1973 IAEA study assumed an 8% discount rate and made "sensitivity" tests of rates ranging from 6% to 10%. In the 1974 study, the discount sensitivity limit was raised to 12%. The IAEA results were not greatly affected by the choice of a discount rate.[28]

---

[27] Cited in Note 4 above. The RJBA report was distributed by the National Technical Information Service of the U.S. Department of Commerce.

[28] IAEA, Market Survey..., 1974 Edition, Table XVI, p. 28.

The IAEA rates of discount may reflect true capital costs to an individual borrower, but probably do not reflect the value to society of alternative uses of the capital. It is this latter rate which should be used if capital scarcities in a country are to be accurately taken into consideration. Use of an 8% discount rate plus the generally conservative assumptions employed in the "medium" RJBA alternatives would mean that 600 MW nuclear plants become competitive with 600 MW oil-fired plants once delivered fuel oil price (in 1974 dollars) had risen to \$6.90. If a 15% discount rate were used, the oil price would have to rise to \$9.40/barrel, while a 20% rate would imply that a 600 MW nuclear plant would not be the preferred choice below a delivered fuel oil price of \$11.40.[29] At 1976 delivered prices for fuel oil of about \$11.50/barrel, this means that even under fairly conservative assumptions, including a 20% rate of discount, 600 MW and larger nuclear plants are probably fully competitive with oil plants in many developing countries. If the original 8% IAEA discount rate were used with the same assumptions, including the plant cost scale factors adopted by the RJBA report, nuclear plants as small as 250 or 300 MW would now be economical. Thus, the "medium" RJBA assumptions <u>in conjunction with an 8% discount rate</u> would produce nuclear expansion projections, at

---

[29] The assumptions upon which these calculations are based are shown in Table 4. They differ from the RJBA "medium" assumptions only in the heat content of oil where a 6.3 instead of a 6.0 million Btu/barrel figure has been used for the present study. With nuclear plant costs of \$712/KWe, and oil of \$420/KWe, the "break-even" oil cost (line 11 in Table 4) is found from:

$$\text{Oil cost } (¢/\text{kwh}) = .47 + 5.555 \text{ CRF}$$

where

$$\text{CRF} = \text{Capital Recovery Factor}$$

$$= \frac{r}{1 - \left(\frac{1}{1 + 4}\right)^{N}}$$

and

## Table 4

### Delivered Electricity Costs from 600 MWe Generating Plant in Developing Country

(1974 prices)

| Line | Nuclear[a] |  | Coal |  | Oil |  |  |
|---|---|---|---|---|---|---|---|
|  | (A) | (B) | (C) | (D) | (E) | (F) | (G) |
| I. Assumptions |  |  |  |  |  |  |  |
| Fuel prices, delivered |  |  |  |  |  |  |  |
| 1. Nuclear, $/lb $U_3O_8$ | $20 | $20 |  |  |  |  |  |
| 2. Coal, $/MT |  |  | $15 | $45 |  |  |  |
| 3. Fuel oil, $/bbl |  |  |  |  | $ 4 | $ 9 | $12 |
| 4. Capital cost of generating plant, $/KWe | 420 | 712 | 548 | 548 | 420 | 420 | 420 |
| 5. Discount rate, % | 12 | 20 | 20 | 20 | 20 | 20 | 20 |
| 6. Capacity factor (CF), % | 65 | 60 | 60 | 60 | 60 | 60 | 60 |
| 7. Heat rate, Btu/kwh | 10229 | 10595 | 8805 | 8805 | 8714 | 8714 | 8714 |
| 8. Heat content of fuel, million Btu/MT |  |  | 27.8 | 27.8 | 6.3 | 6.3 | 6.3 |
| II. Cost Elements (expressed in US¢/kwh) |  |  |  |  |  |  |  |
| A. Generating |  |  |  |  |  |  |  |
| 9. Capital | .92 | 2.72 | 2.09 | 2.09 | 1.60 | 1.60 | 1.60 |
| 10. Operating & maintenance | .06 | .06 | .04 | .04 | .04 | .04 | .04 |
| 11. Fuel | .33 | .47 | .48 | 1.43 | .55 | 1.24 | 1.65 |
| 12. Subtotal | 1.31 | 3.25 | 2.61 | 3.56 | 2.19 | 2.88 | 3.30 |
| B. Transmission and Distribution |  |  |  |  |  |  |  |
| 13. Capital | .57 | .92 | .92 | .92 | .92 | .92 | .92 |
| 14. Losses | .63 | 1.39 | 1.18 | 1.49 | 1.04 | 1.27 | 1.41 |
| 15. Subtotal | 1.20 | 2.31 | 2.10 | 2.41 | 1.96 | 2.19 | 2.33 |
| 16. C. Total, delivered | 2.51 | 5.56 | 4.71 | 5.97 | 4.15 | 5.07 | 5.62 |

[a] Column (A) corresponds to the "IAEA scenario most favorable to nuclear" power, as interpreted by Richard J. Barber Associates in LDC Nuclear Power Prospects, 1975-1980, Chapter 2. (This source is referred to below as "RJBA".) Column (B) represents the RJBA "medium" estimates of nuclear power costs. It is comparable in most of its assumptions to the remaining columns shown for coal and fuel oil.

(CONTINUED)

## Table 4 (CONTINED)

Sources: line 1: Represents mining and milling costs of uranium oxide from RJBA, pp. II-22 and B-7. These costs are comparable to the price usually quoted for uranium but represent only a fraction of the total "fuel cycle" expenditures.

line 2: The $15 figure corresponds to the delivered cost of coal in the U.S. in June 1974 (RJBA, p. 11-19, footnote *). The world foreign trade price in that year was closer to $45/MT or about $1.6 per million Btu.

line 3: The $4/bbl ($.63/million Btu) figure is included solely to give an idea of cost elements prior to the early 1970's. Current (1976) delivered prices are closer to $14 in 1976 prices and to $11.50 in 1974 prices. The intermediate price would represent a 25% reduction from current costs.

line 4: 1000 MWe plant costs are from RJBA, p. 0-37, Figure II-13. They have been multiplied by plant size scale factors of 1.19 for nuclear and 1.13 for fossil plants (Ibid., p. II-18). The oil plant costs include no allowance for $SO_2$ controls.

line 5: 12% is the highest discovered rate used for standard calculations by the IAEA. The AEC uses 15% for U.S. power plant analyses, according to RJBA, and the TVA uses 20% when evaluated fertilizer investment in LDC's (RJBA, p. II-34). The 20% figure was chosen by RJBA for the "medium" scenario and seems a reasonable estimate of anticipated average capital returns in developing countries.

line 6: RJBA, p. II-37, Figure II-13. See also the discussion beginning on p. II-25. The 60% and 65% plant factors are those used by the IAEA in Market Survey for Nuclear Power in Developing Countries, 1974 edition, p. 8, para 4.2.

line 7: RJBA, p. II-20. The nuclear (B) estimate and those for coal and oil are taken from AEC sources.

line 8: Based on "standard" commodities containing about 7,000 kilocalories/kg for coal and 10,560 kilocalories/kg for residual fuel oil. (See World Bank Staff Working Paper No. 229, p. iii.) These are felt to be more consistent with the fuel priced in lines 2 and 3 than are the somewhat lower heat contents employed (but not justified) by RJBA.

line 9: Annualized cost based upon the discount rate, r, from line 5, and the formula:

$$\frac{1.141555\ (\text{line } 4)}{(\text{line } 6)} \quad \frac{r}{1 - \left(\frac{1}{1+r}\right)^{N}}$$

where N = project life in years, assumed equal to 30. See RJBA, Appendix A.

line 10: World Bank estimate: Public Utilities Department Report No. 556a, July 10, 1975.

line 11: Nuclear fuel costs are from RJBA, p. II-37, Figure II-13, multiplied by a plant scale factor of 1.076 (IAEA, Market Survey..., 1974 Edition, p. 4, Table II). The coal (oil) costs equal line 2 (line 3) x line 7 ÷ line 8 ÷ $10^4$.

line 12: Equals lines 9 + 10 + 11.

line 13: Based on an average cost of transmission and distribution of $240 per kw, from Efraim Friedmann, "Financing of Power Expansion for Developing Countries," IBRD, Public Utilities Department PUN 19, October 8, 1975, p. 4. The average ratio of actual to peak demand has been estimated at 60% based on the IAEA estimates of future power needs for 14 countries (Market Survey..., 1974 Edition, p. 7, Table IV.) The analyzed value by analogy with line 9, is thus:

$$\frac{1.14155\ (\$240)}{60} \quad \frac{r}{\left[1 - \left(\frac{1}{1+r}\right)^{N}\right]}$$

line 14: Assumes 25 percent transmission and distribution losses between the generating plant and the final consumer. Equals (line 12 + line 13) ÷ 3.

line 15: Equals lines 13 + 14.

line 16: Equals lines 12 + 15.

current petroleum costs, not greatly different from those of the IAEA.[30]

Table 4 has been constructed to show the general structure of electricity costs, except for those arising from different sizes of generating plants. Because of the high capital costs of distribution and transmission and the large line losses which typically occur once the electricity has been generated, it is seen from the table that generating costs may be little more than half of costs paid by the final consumer. Under the low fuel prices which existed prior to the early 1970's (reflected by the assumptions of column E of the table), capital was the major cost factor. The increasing importance of fuel costs in recent years can be seen in line 11, columns E, F, and G.

The cost structure of nuclear power generation does not differ too greatly from that of oil under the low, historical price assumptions (compare Columns B and E) although the lower capital costs of oil plants would lend them an economic advantage. As fuel costs increase, the capital advantage of oil decreases until, even at a 20% capital discount rate, nuclear plants become more profitable.

The original projections of the IAEA paid little attention to the use of "indigenous" fuels such as coal, lignite, and natural gas, although they did make fairly optimistic assumptions about the growth of hydro generation. The Richard J. Barber Associates' report correctly criticizes the IAEA on this score, and the column (C) estimates of Table 4 show the cost advantage that coal-fired plants may have when indigenous coal supplies are available. (If a country could export its coal, however, at prices

---

[30] The IAEA study found that nuclear plants as small as 150 MWe would, in some cases, be competitive. The 150-1200 MW nuclear plants, however, accounted for only five percent of the estimated 1981-1990 additions to nuclear capacity. (IAEA, Market Survey..., 1974 Edition, Table XIV.) This share of the market is important from the nuclear proliferation standpoint, however. The IAEA study indicates that 19 developing countries would adopt nuclear power only if plants as small as 150 and 200 MW became available.

approaching those of column (D), then nuclear would still be a preferred alternative.)

Table 4 does not deal with questions of risk and uncertainty which may be more severe for the relatively new nuclear technology. There is a distinct possibility, for example, that some nuclear plants (or systems) might have difficulty in operating at a capacity factor as high as 60 percent. Of the world's nuclear powers in 1974, for example, only six (Canada, Netherlands, Belgium, United Kingdom, Spain, and Switzerland) were able to operate at a system capacity factor of about 60 percent or better. Another five countries (USA, Sweden, West Germany, East Germany, and the USSR) were able to average less than 50 percent of capacity.[31] For its "unfavorable to nuclear" scenario, the RJBA study assumed a 50 percent capacity factor. This factor alone in conjunction with a 20% discount rate and the "medium" assumptions of Table 4, would increase minimum nuclear plant size to at least 850 MWe at a delivered oil price of $11.50 per barrel. Adding the assumption of a further 26 percent escalation in plant costs of both nuclear and oil-fired generation would raise the minimum plant size to 1200 MWe.

It is unlikely, however, that plant costs in real terms (that is, in relationship to the general level of prices in international trade) are likely to increase as much as assumed under the most conservative RJBA alternative. (Under this alternative, the costs of a 1000 MWe station would be 2.1 times that assumed by the IAEA for nuclear plants and 2.4 times that assumed for oil-fired installations.)[32] It is also to be expected

---

[31] United Nations, World Energy Supplies, 1950-1974, op. cit., Table 18.

[32] Richard J. Barber Associates, op. cit., p. II-37, Figure I-13. See also IAEA, Market Survey..., 1974 Edition, p. 27, Table XV, where the costs are specified as being in January 1, 1974 U.S. dollars. (The RJBA report is rather vague at times about the year in which prices are quoted, but they seem to be generally for 1974.)

that, as time goes by, the alternative returns to capital in developing countries will fall, thus reducing the corresponding rate of discount.

Two further points should be made about future costs of power generation. The first is the distinct possibility, examined in the RJBA study and assumed as an alternative in at least one World Bank document, that crude oil prices will fall in the future.[33] The present reality (July 1976) is that crude oil prices in real terms have probably fallen slightly from their high point of early 1974 and that this situation is being tolerated by the OPEC countries at least partly out of fear of encouraging future energy conservation measures or causing economic slowdowns if oil prices were to be increased further. The "overhang" of surplus OPEC production capacity seems likely to continue for a number of years, contributing to strains within the cartel. The cartel might even find it advantageous to adopt a two-price system under which LDC's would pay less. This might appeal to the OPEC members' desire to aid development in the world's poorer countries, as well as to preserve a petroleum market in those countries which might otherwise be lost to nuclear power.

The second point is that further technological change in conventional power generation is still a possibility. As past changes have tended to conserve capital, so future changes may be expected which conserve the new dominant cost element, fuel. The easiest way that this can be done, with no new technological requirements at all, is to combine electrical generation with the provision of process heat for industry. Energy-use efficiencies by this step, even with relatively small power plants, may

---

[33] Richard J. Barber Associates, op. cit., p. III-29; and World Bank Staff Working Paper No. 229, op. cit., p. 2.

immediately be increased from the single-use efficiency of 30 to 40 percent to two-thirds or better.[34] A system of small power plants converting two-thirds of their fuel into useful work may have been uneconomical when energy costs were low (because of the higher capital costs of small plants) but may become more than competitive with single-purpose 1000 MWe plants burning high-cost fuel at one-half the small-plant-system efficiency.

In the case of this option, the innovations needed are institutional rather than technological. The role of industrial (as opposed to public) power generation would have to expand with industries being encouraged to buy peak power from a common grid and sell surplus power to the same grid. This type of arrangement is generally discouraged in countries with public utilities organized as they are in the United States and the United Kingdom, and developing countries are prone to regard industrial generators as high-cost indicators of "unsatisfied" public utility demand. Similarly, individual industrial firms cannot afford to generate their own electricity (in competition with a public utility) unless they can buy and sell freely from a common grid and thus avoid the high capital costs of peaking and standby capacity. If such an arrangement is permitted by electric grid managers, then industrial self-generation of electricity can be expected to become considerably more widespread.

---

[34] E. Bohm, "Nuclear Power Plants for Combined Power and Heat Supply," in Small and Medium-Size Power Reactors, Proceedings of a Panel, Vienna, June 24-28, 1968 (Vienna: IAEA, 1969). Nuclear-based complexes of industrial and agricultural activity ("nuplexes") were a fond dream of nuclear scientists in the 1960's. See J.W. Michel and J.E. Mrochek, "Recent Development in the Agro-Industrial Complex Studies at Oak Ridge National Laboratory," in Nuclear Energy Costs and Economic Development, Proceedings of a Symposium Istanbul, October 20-24, 1969 (Vienna: IAEA, 1970). This idea seems to have been discouraged by the recent concern over reactor safety, but an adaptation of the multi-purpose idea to small thermal plants would make good economic sense at today's fuel prices. See also A.A. Delayannis, "Nuclear Energy Centers and Agro-Industrial Complexes," Technical Reports Series 140 (Vienna: IAEA, 1972).

## Can Developing Countries Afford the Economic Cost of Nuclear Power?

This question is sometimes raised because the power needs for economic development are known to increase faster than the rate of Gross Domestic Product and because the capital costs of nuclear power are so much greater than those of fossil generation. The question, however, has little meaning if it is used to raise doubts about the wisdom of a nuclear power choice made using the type of economic analysis employed by both the IAEA and the Richard J. Barber Associates. Capital scarcities are explicitly taken into consideration in these analyses through the use of the discount factor. The question posed is, given an assumed shortage of capital, which of several systems will be least expensive? If nuclear is the answer, then if a country cannot "afford" nuclear power, it will be even less able to afford an alternative source of power. (The controversy between the IAEA and RJBA on this point, it should be noted, revolves not over the use of a capital discount factor but the exact rate chosen. The IAEA rate most closely reflects the financial cost of capital borrowing while the higher rate proposed by RJBA more nearly reflects the economic worth of capital to the country as a whole.)

Special problems may exist when a country is faced with a particularly actue difficulty in earning foreign exchange. This may be handled analytically by assigning a "shadow" value to foreign exchange which is higher than that indicated by the current foreign exchange rate and which more nearly reflects longer-run scarcity. This, indeed, was done in a number of IAEA country analyses.[35] The RJBA report also dealt with this point, suggesting that foreign exchange shortages might make the exploitation of indigenous energy sources more attractive. The study also suggested

---

[35] International Atomic Energy Agency, Market Survey...,: General Report, op. cit., p. K-2.

that if a country had to finance power system expansion entire or largely from its own foreign exchange holdings, the larger first-cost of nuclear power might argue for choosing fossil fuel instead. The numercial example used in the RJBA report to demonstrate this latter point, however, leads to exactly opposite conclusions if foreign borrowing is possible and if the fossil fuel must be imported. In the case of nuclear- and oil-fired units of 600 MWe capacity and assuming a $10 per barrel oil import cost, then the foreign exchange savings in oil import costs would offset the higher initial foreign exchange costs of nuclear construction and nuclear fueling after only 3.4 years of operation.[36] Thus, in this case, a shortage of foreign exchange might reinforce the economic advantage of a nuclear over an oil-fired plant.

It is true that electric power consumption and hence power investment in general can be expected to increase at rates faster than GDP. This means only that power investment may account for a larger proportion of total investment and perhaps of foreign exchange borrowings. Even with a complete conversion to nuclear power, the higher investment costs of nuclear plants would lead to only a very small increase in the total share of investment in GDP. Nuclear plants having a 70 percent higher cost than oil plants (see line 4 in Table 4) might lead to a 50 percent increase in energy sector investment, but this should imply no more than a 3 percent <u>increase in total</u> investment, say from 17 percent of GDP to 17-1/2 percent.[37]

[36] Richard J. Barber Associates, <u>op</u>. <u>cit</u>., pp. II-50 - II-51.

[37] This calculation assumes that (a) nuclear investment for the same size plant esceeds its conventional alternative by 70%, (b) energy investment as a share of GDP is 1.8% and, under conventional power plant conditions, would consist of 70% power investment, of which 60% would be for generating plants.

This would be an increased cost to the country only in a short-run accounting sense, furthermore, since if nuclear power were truly the most economic choice, then the higher capital investment would eventually be offset by lower outlays for fuel.

Thus, there may be some institutional problems in shifting a larger proportion of foreign borrowing into the electric power sector,[38] but there is no reason why the developing countries, if they can afford electric power at all, cannot afford nuclear electric power when the economic advantage lies with nuclear power.

What about situations where initial assumptions turn out to have been optimistic, and nuclear power ends up by costing more than a conventional alternative? Or those cases where a country opts for nuclear power on strategic grounds or because it believes that it must gain experience with nuclear power even though it may not yet be economic? What are the economic costs to the country in these situations?

The answer depends partly on the cost difference between nuclear and conventional power and partly on the scale of the nuclear experiment. Given the most anti-nuclear assumptions of the RJBA study, including that of a 50 percent plant capacity factor and a 25 percent rate of discount, a country would lose $25 million annually if it were to build a 1000 MWe nuclear plant in place of a 1000 MW oil-fired plant, and if oil were worth

---

[38] These are discussed by Efrain Friedmann in "Financing of Power Expansions for Developing Countries," op. cit., in Notes to Table 4. This paper has been published in International Atomic Energy Agency Bulletin, Vol. 17, No. 6 (Dec. 1975).

\$11.50 per barrel.[39] The nuclear plant, nevertheless, might still be financially profitable if the actual cost of borrowing were lower than 25 percent. If the actual interest rate were 12 percent, for example, the nuclear plant might show a "financial" profit of about \$11 million per year when compared with the oil-fired alternative. (The economic cost to the country, however, would nevertheless be \$25 million per year if the difference in the two investment costs could have been invested elsewhere at a 20 percent rate of return.)

---

[39] These calculations are based upon the "actualized cost" procedures used for the RJBA. The annual cost of producing power in U.S. cents per kilowatt-hour, under each alternative is:

$$\text{Oil:}\quad \frac{\$460\ F_o(\text{CFR})1.14155}{\text{CF}} + \frac{\$11.50\ (8714)}{10^4\ (6.3)} + .04$$

$$\text{Nuclear:}\quad \$745\ F_n(\text{CRF})1.14155 + .517\ F_{nf} + .06$$

$$\text{where:}\quad \text{CRF} = \text{capital recovery factor} = \frac{r}{1 - \left(\frac{1}{1+r}\right)^N}$$

r = discount rate in %/100

N = 30 = estimated plant life, years

CF = plant capacity factor, in %

8714 = heat rate for oil plants, Btu/kwh

\$11.50 = price of oil, \$/bbl

6.3 = heat content of oil, million Btu/bbl

\$460 and \$745 = capital costs per KWe for 1000 MWe oil and nuclear plants, respectively

.04 and .06 = operating and maintenance costs (World Bank estimates) for oil and nuclear plants, respectively, in ¢/kwh

$F_o$, $F_n$, and $F_{nf}$ = plant and fuel cost scale factors for various plant sizes as follows:

| Plant Size MWe | Plant Size Scale Factors Nuclear ($F_n$) | Plant Size Scale Factors Fossil ($F_o$) | Fuel Cycle Cost Plant Size Scale Factor, Nuclear ($F_{nf}$) |
|---|---|---|---|
| 100 | 2.80 | 1.70 | 1.16 |
| 200 | 2.10 | 1.45 | 1.14 |
| 400 | 1.50 | 1.23 | 1.09 |
| 600 | 1.19 | 1.13 | 1.05 |
| 800 | 1.09 | 1.05 | 1.03 |
| 1000 | 1.00 | 1.00 | 1.00 |
| 1200 | 0.92 | 0.95 | 0.96 |

Source: RJBA, Appendix A, p. A-7

Because the higher capital costs per kilowatt outweigh gains from producing a smaller amount of electricity, a 200 MWe nuclear plant under the above conditions might be more costly than a 1000 MWe plant. The cost disadvantage of the smaller plant when compared to an oil plant of the same size would amount to $36 million per year. Even with a money cost of only 12 percent, the financial losses to the country would be on the order of $14 million annually.

A $14 million annual financial loss would be large in absolute terms, but small in relationship to the government budgets of most developing countries. It might be regarded by many countries as a reasonable price to pay for joining the Nuclear Club.

## Conclusions

The preceding sections have shown that energy use by developing countries can be expected to increase greatly in the future, even under rather conservative assumptions about economic growth rates and the growth of heavy industry. Conventional energy resources remain relatively plentiful, and prospects for further increases are good. Energy prices may remain at the high levels of the past few years, but are unlikely to increase further in real terms, at least for the next decade. There is at least some possibility that crude oil prices may drop in relative terms, and this possibility may be higher for developing countries than for developed countries.

A developing country's choice among competing fuels for power generation can be expected to increasingly favor indigenous sources if only to conserve scarce foreign exchange. Coal-powered plants based on domestic deposits probably will have a distinct cost advantage over both nuclear and oil. At the current price of oil (assumed to be about $11.50 f.o.b. Persian Gulf in 1976 dollars and about the same price delivered in 1974 dollars), nuclear plants in most developing countries would appear to be more economic than oil-fired units when plant size is 600 MWe or greater. Given the known cost factors, the higher degree of uncertainty about nuclear plant costs and operating characteristics, as well as the possibility of some further erosion in the price of imported oil, oil-fired plants appear preferable to nuclear in smaller plant sizes. This advantage could be further solidified through future technological or institutional changes which result in improved system-fuel-use efficiencies.

These cautionary remarks, however, should not be interpreted as meaning that the future LDC market for nuclear plants will be unimportant. A large fraction of future LDC power expansion will be most economical using large nuclear installations even under fairly conservative assumptions. To discourage the use of nuclear power in these markets would be to significantly increase the future cost of power generation.

The existing International Atomic Energy Agency projections of the LDC nuclear market are summarized in Table 5. Countries in this table are grouped into those whose future systems would mainly employ plants of 600 MWe and larger, and countries whose maximum size units would lie below this limit. It can be seen that the size of the nuclear market would remain large, although the number of nuclear-producing countries would be cut by two-thirds, even if all plants of less than 600 MWe should turn out to be uneconomical.

The IAEA projections, however, are probably optimistic. They, accordingly, have been adjusted downward in Table 6 to reflect (a) lower rates of anticipated electric power growth for certain countries or groups of countries; (b) the increased use of indigenous fuel resources, and (c) the elimination of most nuclear plants below 600 MWe. The result is to lower the nuclear power estimate for 1990 by more than one-half and for the year 2000 by almost half. (Note that the elimination of smaller plants accounts for a relatively small fraction of these decreases.) Of the 244,000 MWe downward adjustment in nuclear power for 2000, 138,000 MWe would be compensated for by a higher use of indigenous fossil fuels. (The increased exploitation of geothermal resources will also undoubtedly occur and should be included in these totals.) Another 106,000 MWe may simply not be needed if the demand assumptions discussed earlier in this paper should turn out to be accurate.

The trend towards increased use of nuclear installations, however, is nevertheless apparent from Table 6, even though the nuclear share does not increase as rapidly as with the IAEA projections. Nuclear power

Table 5

International Atomic Enery Agency Projections of Total and Nuclear Electrical Generating Capacity, Developing Countries with Nuclear Potential, 1990 and 2000

| Country group and nuclear plant size* | No. of Countries | 1990 Capacity ('000 MWe) | | | | No. of Countries | 2000 Capacity ('000 MWe) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fossil | Nuclear | Hydro | Total | | Fossil | Nuclear | Hydro | Total |
| I. NON-OPEC | | | | | | | | | | |
| Low income | | | | | | | | | | |
| Large nuclear | 2[a] | 29.2 | 36.3 | 47.8 | 113.3 | 3[c] | 30.3 | 145.9 | 67.3 | 243.5 |
| Small nuclear | 3[b] | 1.6 | 5.2 | 3.2 | 10.0 | 2[c] | 3.0 | 15.3 | 3.9 | 22.2 |
| Middle income | | | | | | | | | | |
| Large nuclear | 4[d] | 13.2 | 23.3 | 8.9 | 45.4 | 4 | 14.2 | 58.7 | 11.8 | 84.7 |
| Small nuclear | 6[e] | 1.6 | 1.6 | 3.7 | 6.9 | 6 | 3.0 | 6.5 | 5.9 | 14.5 |
| Higher income | | | | | | | | | | |
| Large nuclear | 6[f] | 32.3 | 57.4 | 72.8 | 162.5 | 9[h] | 44.1 | 189.6 | 103.1 | 336.8 |
| Small nuclear | 14[g] | 18.3 | 16.6 | 10.2 | 45.1 | 11[h] | 13.9 | 30.9 | 6.3 | 51.1 |
| II. OPEC | | | | | | | | | | |
| Large nuclear | 2[i] | 12.8 | 14.4 | 11.4 | 38.6 | 3[k] | 14.0 | 42.1 | 22.8 | 78.9 |
| Small nuclear | 8[j] | 6.7 | 5.5 | 2.9 | 15.1 | 7[k] | 8.2 | 12.2 | 2.3 | 22.7 |
| III. OTHER | | | | | | | | | | |
| Turkey (Large) | 1 | 3.4 | 5.0 | 10.5 | 18.9 | 1 | 3.5 | 23.3 | 13.6 | 40.4 |
| Cuba (Small) | 1 | 2.6 | 2.1 | - | 4.7 | 1 | 2.6 | 5.5 | - | 8.1 |
| IV. ALL DEVELOPING COUNTRIES | | | | | | | | | | |
| Large nuclear | 15 | 90.9 | 136.4 | 151.4 | 378.7 | 20 | 106.1 | 459.6 | 218.6 | 784.3 |
| Small nuclear | 32 | 30.8 | 31.0 | 20.0 | 81.8 | 27 | 30.7 | 70.4 | 17.5 | 118.6 |
| TOTAL | 47 | 121.7 | 167.4 | 171.4 | 460.5 | 47 | 136.8 | 530.0 | 236.1 | 902.9 |

Source: International Atomic Energy Agency, *Market Survey for Nuclear Power in Developing Countries*, 1974 Edition (Vienna: IAEA, 1974) Tables XIII and XIV; and Richard J. Barber Associates, *LDC Nuclear Power Prospects, 1975-1990: Commercial, Economic and Security Implications* (Washington, 1975), pp. II-35c, 35d and 42b.

*"Large nuclear" countries are those with projected nuclear plants in the year shown of 600 MWe or more. "Small nuclear" countries are projected to have no nuclear plants in the year shown which are as large as 600 MWe.

[a] India and Pakistan. [b] Bangladesh, Vietnam (South), and Uganda.

[c] Bangladesh shifts from the small to the large category.

[d] Egypt, South Korea, Philippines, and Thailand.

[e] Cameroon, Ghana, Morocco, Syria, Bolivia, and El Salvador.

[f] Argentina, Brazil, Colombia, Mexico, Taiwan and Singapore.

[g] Peru, Hongkong, Chile, Malaysia, Israel, Uruguay, Jamaica, Lebanon, Costa Rica, Dominican Republic, Panama, Tunisia, Guatemala, and Zambia.

[h] Countries shifting from small to large are: Chile, Peru and Hong Kong.

[i] Iran and Venezuela.

[j] Indonesia, Kuwait, Iraq, Nigeria, Algeria, Ecuador and Saudi Arabia

## Table 6

## Proposed Adjustments to IAEA Projections of Nuclear and Other Generating Plant Capacity, Developing Cointries with Nuclear Potential, 1990 and 2000

| | Installed Capacity ('000 MWe) | | | |
|---|---|---|---|---|
| **1990** | Fossil | Nuclear | Hydro | Total |
| IAEA Total[a] | 121.7 | 167.4 | 171.4 | 460.5 |
| (% by fuel type) | (27%) | (37%) | (37%) | (100%) |
| Adjustments | | | | |
| Increased exploitation indigenous fuel: | | | | |
| Coal (Bangladesh, Indonesia, Turkey) | 6.2[b] | -6.2 | 0 | 0 |
| Natural gas (Bangladesh) | 2.1[c] | -3.8[c] | 0 | -1.7[c] |
| Reduced growth rates: | | | | |
| India[d] | 15.0 | -22.4 | -14.6 | -22.0 |
| Higher income, non-OPEC[e] | 6.0 | -46.7 | 0 | -40.7 |
| Elimination most nuclear plants below 600 MWe | 14.4 | -14.4[f] | 0 | 0 |
| Subtotal, adjustments | 43.7 | -93.5 | -14.6 | -64.4 |
| Adjusted Totals, 1990 | 165.4 | 73.9 | 156.8 | 396.1 |
| (% by fuel type) | (42%) | (19%) | (39%) | (100%) |
| **2000** | | | | |
| IAEA Total[a] | 136.8 | 530.0 | 236.1 | 902.9 |
| (% by fuel type) | (15%) | (59%) | (26%) | (100%) |
| Adjustments | | | | |
| Increased exploitation indigenous fuel: | | | | |
| Coal (Bangladesh, Indonesia, Turkey) | 18.7[b] | -18.7 | 0 | 0 |
| Natural gas (Bangladesh) | 3.6 | -3.6 | 0 | 0? |
| Reduced growth rates: | | | | |
| India[d] | 63.0 | -94.0 | 0 | -31.0 |
| Higher income, non-OPEC | 13.4 | -88.4 | 0 | -75.0 |
| Elimination most nuclear plants below 600 MWe | 39.5 | -39.5 | 0 | 0 |
| Subtotal, all adjustments | 138.2 | -244.2 | 0 | -106.0 |
| Adjusted Totals, Year 2000 | 275.0 | 285.8 | 236.1 | 796.9 |
| (% by fuel type) | (34%) | (36%) | (30%) | (100%) |

[a](For footnotes, see following page.)

## Table 6

### Proposed Adjustments to IAEA Projections of Nuclear and Other Generating Plant Capacity, Developing Cointries with Nuclear Potential, 1990 and 2000

| | Installed Capacity ('000 MWe) | | | |
|---|---|---|---|---|
| | Fossil | Nuclear | Hydro | Total |
| **1990** | | | | |
| IAEA Total[a] | 121.7 | 167.4 | 171.4 | 460.5 |
| (% by fuel type) | (27%) | (37%) | (37%) | (100%) |
| Adjustments | | | | |
| Increased exploitation indigenous fuel: | | | | |
| Coal (Bangladesh, Indonesia, Turkey) | 6.2[b] | -6.2 | 0 | 0 |
| Natural gas (Bangladesh) | 2.1[c] | -3.8[c] | 0 | -1.7[c] |
| Reduced growth rates: | | | | |
| India[d] | 15.0 | -22.4 | -14.6 | -22.0 |
| Higher income, non-OPEC[e] | 6.0 | -46.7 | 0 | -40.7 |
| Elimination most nuclear plants below 600 MWe | 14.4 | -14.4[f] | 0 | 0 |
| Subtotal, adjustments | 43.7 | -93.5 | -14.6 | -64.4 |
| Adjusted Totals, 1990 | 165.4 | 73.9 | 156.8 | 396.1 |
| (% by fuel type) | (42%) | (19%) | (39%) | (100%) |
| **2000** | | | | |
| IAEA Total[a] | 136.8 | 530.0 | 236.1 | 902.9 |
| (% by fuel type) | (15%) | (59%) | (26%) | (100%) |
| Adjustments | | | | |
| Increased exploitation indigenous fuel: | | | | |
| Coal (Bangladesh, Indonesia, Turkey) | 18.7[b] | -18.7 | 0 | 0 |
| Natural gas (Bangladesh) | 3.6 | -3.6 | 0 | 0? |
| Reduced growth rates: | | | | |
| India[d] | 63.0 | -94.0 | 0 | -31.0 |
| Higher income, non-OPEC | 13.4 | -88.4 | 0 | -75.0 |
| Elimination most nuclear plants below 600 MWe | 39.5 | -39.5 | 0 | 0 |
| Subtotal, all adjustments | 138.2 | -244.2 | 0 | -106.0 |
| Adjusted Totals, Year 2000 | 275.0 | 285.8 | 236.1 | 796.9 |
| (% by fuel type) | (34%) | (36%) | (30%) | (100%) |

[a] (For footnotes, see following page.)

# Table 6
(cont.)

Footnotes

[a] International Atomic Energy Agency totals from Table 5.

[b] Additional fossil fuel plant capacity, over and above that projected by the IAEA, representing exploitation of indigenous coal reserves such that one-half of coal is consumed by the year 2000:

('000 MWe)

| | 1974 Thermal Capacity (UN, J-19) | Estimated Coal Additions by 2000* | Total Yr. 2000 Thermal Capacity | Yr. 2000 Thermal Cap. est. by IAEA** | Net*** Increase |
|---|---|---|---|---|---|
| India | 12.0 | 78.0 | 90.0 | 27.0 | 63.0 |
| Brazil | 3.0 | 13.5 | 16.5 | 3.1 | 13.4 |
| Turkey | 2.1 | 12.5 | 14.6 | 3.5 | 11.1 |
| Indonesia | .8 | 4.0 | 4.8 | 1.1 | 3.7 |
| Bangladesh | .7 | 4.3 | 5.0 | 1.1 | 3.9 |

*Estimates made by Richard J. Barber Associates. See LDC Nuclear Power Prospects, 1975-1990, op. cit., pp. II-40, 43.

**Market Survey for Nuclear Power in Developing Countries, 1974 Edition, Table XIII.

***For the year 2000. The 1990 net increase is assumed to be one-third of the amounts shown.

[c] Represents increased gas plant capacity and decreased total generating capacity (for 1990). Compare the IAEA 1974 Market Survey..., with IAEA, Nuclear Planning Study for Bangladesh (Vienna: IAEA, 1975), p. 131, Table XV-2.

[d] See text for a discussion of the Indian electricity consumption estimates. Changes shown here assume that Indian generating capacity grows as follows:

| | 1974-1980 | 1980-1990 | 1990-2000 |
|---|---|---|---|
| Total capacity | 8.6% p.a. | 9.0% p.a. | 9.0% p.a. |
| Fossil fuels | 8.0 | 8.0 | 8.0* |
| Nuclear | IAEA est.** | 8.0 | 14.3 |
| Hydro | Residual | residual | IAEA est.** |

*Conforms with RJBA estimate of increased coal-burning capacity. See note b.

**Market Survey, 1974 Edition.

[e] See text. Assumes that for the countries with nuclear potential in this subgroup, generating capacity increases at the same rate as does electric consumption for the total subgroup. From Table 3, this is seen to be about 7.0% p.a. during 1974-80 and 6.5% p.a. during 1980-2000. IAEA estimates were used for hydro and fossil capacity except that increased coal capacity was added for Brazil as shown in note b above. Nuclear capacity was then taken as a residual. The revised growth rates for capacity increases are thus:

| | 1980-1990 | 1990-2000 |
|---|---|---|
| Total | 6.5% p.a. | 6.5% p.a. |
| (cf IAEA est.*) | (8.6%) | (6.5%) |
| of which: Hydro | 7.3 | 2.8 |
| Fossil | 2.2 | 2.6 |
| Nuclear | 22.5 | 16.4 |
| (cf. IAEA est., nuclear*) | (29.2) | (11.5) |

* Market Survey..., 1974 Edition

[f] Plants of under 600 MWe capacity. Equals sum of all "small nuclear" countries from Table 5, except for the higher-income, non-OPEC subgroup where the nuclear reductions described in the previous footnote would probably have already eliminated most of the smaller nuclear systems. Also not included are minor amounts of small-plant capacity in Thailand and Singapore (1990) and in Bangladesh, Thailand, and Indonesia (2000).

according to Table 6 might represent 19 percent of total generating capacity in 1990 and 36 percent by the year 2000. Although country detail has not been prepared for the Table 6 projections, it is assumed that the same "large nuclear" countries will be producing nuclear power in the future as under the IAEA projections. In 1990, the list should include India, Pakistan, Taiwan, Republic of Korea, Iran, Turkey, Egypt, the Philippines, and possibly Thailand and Singapore. The Latin American producers would consist of Mexico, Brazil, Argentina, Venezuela, and probably Colombia (although Colombian coal remains a largely unexploited and unexplored alternative). By the year 2000, the LDC nuclear group should have added Hong Kong, Singapore, Peru, and Chile. Active exploitation of indigenous gas and coal resources may raise questions about the nuclear role of Bangladesh. Indonesia is firmly anticipating a nuclear future but may have second thoughts about using its reportedly very large coal reserves whose only presently contemplated use is for exports to Japan.

Whether the nuclear producing group is enlarged beyond the above list of 20 countries depends very much upon the future cost and availability of smaller-size nuclear plants and upon how much individual countries may be willing to pay to join the Nuclear Club. The possibility of a future market for small (especially 300 MWe and under) nuclear plants is dismissed almost unequivocably by the U.S. nuclear industry.[40] The grounds for dismissal involve probable high cost and the fact that such reactors are not yet available commercially. The IAEA, however, has been

---

[40] Richard J. Barber Associates, *op*. *cit*., p. V-72 ff.

actively promoting the idea of a small plant market for a number of years. It reported in early 1976 that

> Three organizations (Technicatome, France; Interatom, F.R. Germany, and UKAEA and/or Fairey Engineering of UK), which have designs for plants in the size range 92-345 MWe have informed the IAEA that they would respond reasonably promptly to a bid invitation. The reactor systems (pressurized light water and steam generating heavy water) which these organizations propose are stated to be based on present, proven reactor technology. The light water reactors are essentially land-based versions of French and German ship propulsion reactors while the heavy water reactor design is based upon the SGHWR plant at Winfrith in the United Kingdom. [41]

None of the three firms mentioned are currently major suppliers for the nuclear electric power market, but this may increase their appetite for a small and presently neglected share of that market.

---

[41] André-Jacques Polliart and Eli Goodman, "Prospects for Utilization of Nuclear Power in Africa," International Atomic Energy Agency Bulletin, Vol. 18, No. 1 (February 1976), p. 43.