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Global Energy Futures and Human Development: A Framework for Analysis

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By

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The world is very different now. For man holds in his mortal hands the power to abolish all forms of human poverty and all forms of human life.

To those people in the huts and villages of half the globe, struggling to break the bonds of mass misery, we pledge our best efforts to help them help themselves.

-- President John F. Kennedy, Inaugural Address.
January 20, 1961

…we will be forced increasingly to define security more broadly…

And we must advance a larger agenda to fight the poverty that breeds conflict and war.

Until we confront the iron link between deprivation, disease, and war, we will never be able to create the peace that the founders of the United Nations dreamed of.

-- President William J. Clinton, Remarks to the United Nations Security Council
September 7, 2000

ABSTRACT

This paper explores the relationship between measures of human well-being and consumption of energy and electricity. A correlation is shown between the United Nations' Human Development Index (HDI) and annual per-capita electricity consumption for 60 populous countries comprising 90% of the world's population. In this correlation, HDI reaches a maximum value when electricity consumption is about 4,000 kWh per person per year, well below consumption levels for most developed countries but also well above the level for developing countries. The correlation with electricity use is better than with total primary energy use. Global electricity consumption associated with a "Human Development Scenario" is estimated by adding to U.S. Department of Energy projections for the year 2020 increments of additional electricity consumption sufficient to reach 4,000 kWh per capita on a country-by-country basis. A roughly constant ratio of primary energy consumption to electric energy consumption is observed for countries with high levels of electricity use, and this ratio is used to estimate global primary energy consumption in the Human Development Scenario. The Human Development Scenario implies significantly greater global consumption of electricity and primary energy than do projections for 2020 by the DOE and others.

Introduction: Energy, Human Development, and Conflict

The relationships among energy consumption, economic growth, standard of living, and the potential for conflict have attracted the attention of a number of researchers.

Writing in the January/February 2000 issue of Foreign Affairs, Richard Rhodes and Denis Beller[1] cite, as a national security issue, the need for increased energy production in the developing countries to enable their populations to escape from human misery and minimize the potential for violence. “Development depends on energy, and the alternative to development is suffering: poverty, disease, and death. Such conditions create instability and the potential for widespread violence. National security therefore requires developed nations to help increase energy production in their more populous developing counterparts.”

Jose Goldemberg,[2] writing in Science in 1995, observes that, in 1993, 75% of the world’s population, living in the less developed countries (LDCs), used only about 30% of the world’s commercial energy. Conversely, the 25% of the population that live in industrialized countries accounted for 70% of global energy consumption. But Goldemberg projects that by about 2010 energy consumption in the LDCs will surpass that in the industrialized countries because of high population and economic growth in the LDCs. “For developing countries, development means satisfying the basic human needs of the population, including access to jobs, food, health services, education, housing, running water, and sewage treatment. The lack of access of the majority of the people to such services provides fertile ground for political unrest, revolution, and the hopelessness and despair that lead to emigration to industrialized countries in the search for a better future.”

Goldemberg cites quantitative measures of human well-being, some of which will be of interest here. “Despite the enormous progress that has been made around the world in all areas during the past few decades, the fact still remains that in poor developing countries, life expectancy is 30% shorter, infant mortality reaches numbers above 60 deaths per 1000 live births (compared with less than 20 in industrialized countries), illiteracy is higher than 40%, the total fertility rate increases dramatically to five or six children as compared with two in industrialized countries (which is just enough to keep the population in equilibrium), there is a high degree of pollution due to lack of sanitation, and more than 2 billion people lack access to electricity.”

Over a quarter of a century ago, also in Science, Roger Revelle[3] described the historical contribution of energy in shaping the human condition. “All ancient civilizations, no matter how enlightened or creative, rested on slavery and on grinding human labor, because human and animal muscle power were the principal forms of energy available for mechanical work. The discovery of ways to use less expensive sources of energy than human muscles made it possible for men to be free.”

Chauncey Starr et al.[4] have pointed to anticipated large increases by 2060 in the use of primary energy (by a factor of 2.4) and electricity (by a factor of 4.7) even with full conservation, driven by high population and economic growth rates in developing countries.

There is, of course, the reverse aspect of the energy-development-conflict relationship. Care must be taken with energy development, as with all development, to maintain environmental sustainability. The roots of conflict may also be found in scarcity that results from environmental degradation. Thomas Homer-Dixon[5] counts rising energy consumption and global warming as two of nine observable physical trends in the global human-ecological system.*

The main purposes of this paper are, first, to describe quantitatively, or at least semi-quantitatively, the relationship between energy use and measures of human development, and second, to use this relationship to estimate future global energy consumption levels associated with high human development criteria. In other words, we want to define a "Human Development Energy Scenario" and estimate the associated global energy consumption. The standard-of-living criteria which are of interest here include some of those cited by Goldemberg, such as longevity and literacy, rather than those directly associated with energy use, such as vehicle miles traveled or building climate-conditioning degree-days.

M.S. Alam et al.[6] correlated quality-of-life data with per-capita electrical energy use for 112 countries and developed mathematical formulae to describe these correlations for life expectancy, literacy, and infant mortality. Their data for electricity are taken from a 1976 United Nations report that compiled data through 1974. In this work, we find that electrical energy consumption is more significant than total primary energy consumption. Here we use more recent data (1997) and attempt to extend the analysis to project global electric energy consumption for 2020 associated with a high human development index as defined by the United Nations. For countries with relatively high levels of per-capita electricity consumption, we observe that the ratio of total primary energy use to electric energy use is roughly constant. We will use a conservative value for this ratio to project global total primary energy use in 2020 as well.

The United Nations' Human Development Index

Since 1990, the United Nations has compiled and published annually statistics on indices of human development and the environment ("human development indicators") including population and demographic trends; life expectancy, nutrition, and health; income and poverty; energy use; education; mortality rates; access to safe water and sanitation; carbon dioxide emissions; etc. The 1999 report includes data for 174 countries.[7]

The UN reports also include a calculated "Human Development Index" for each country. This index combines data for standard of living, represented by a discounted value of gross domestic product (GDP) per-capita); longevity; and educational attainment.† The reports explain in detail how the index is computed. The HDI represents a combination of several indices, not just one, and is therefore a useful measure of

* The others, according to Homer-Dixon, are human population growth, stratospheric ozone depletion, rising cropland scarcity, tropical deforestation, rising scarcity of freshwater, decline of fish stocks, and loss of biodiversity.

† The Human Development Index (HDI): "The HDI is based on three indicators: longevity, as measured by life expectancy at birth; educational attainment, as measured by a combination of adult literacy (two-thirds weight) and the combined gross primary, secondary and tertiary enrolment ratio (one-third weight); and standard of living, as measured by real GDP per capita (PPP$)."

"human development." It has the additional advantage that two-thirds of the index weight represents attributes that are not directly economic (and, as shown in Appendix B, the index can be easily modified to remove the GDP component that accounts for the remaining one-third). Nor are these attributes associated directly with energy use, as are vehicle miles traveled and space conditioning. The table in Appendix A presents ranges of values and average values for each of the four human development indicators that make up the HDI in high, medium, and low human development categories as classified by the UN. For example, the average life expectancy in countries with an HDI of 0.8 or greater is 77.0 years (range 71.7–80.0), with an HDI of 0.5–0.8 it is 66.6 years (range (44.1–75.7), and with an HDI below 0.5 it is 50.6 years (range 37.2–60.7).

The Global Study Sample

To simplify calculations while retaining global significance, a sample of 60 populous nations has been selected for analysis. These are the 60 most populous countries in the world, not including Taiwan, Afghanistan, and North Korea, for which the UN does not report human development indicators or indices. This 60-nation sample, totaling 5.7 billion people, accounted for about 90% of the world's population, primary energy consumption, and electricity consumption in 1997. In the year 2020, these 60 nations are projected to account for 90% of the world's population and 90% of the world's electricity consumption. Estimates of electricity consumption are based on the U.S. Department of Energy's Reference Case projection,[8] and population projections are taken from the U.S. Census Bureau's International Data Base (IDB).[9]

The Human Development Index and Its Relation to Electricity Consumption: An Electricity Threshold for Maximum HDI

The United Nations' Human Development Index is plotted against annual per-capita electricity consumption for 60 countries in Figure 1. These data are for 1997. Significantly, there is a threshold at about 4,000 kWh per capita, corresponding to an HDI of 0.9 or greater, in the relationship between HDI and electricity consumption. Although four countries with consumption levels somewhat above 4,000 kWh per capita have an HDI below 0.9,[*] no country with annual electricity consumption below 4,000 kWh per person has an HDI of 0.9 or greater. Above 5,000 kWh per capita, no country has an HDI below 0.9. Furthermore, as electricity consumption increases above 4,000 kWh, no significant increase in HDI is observed. (Electricity consumption above 4,000 kWh per person per year is associated with increasing GDP per capita. However, because the calculation of the UN's Human Development Index discounts high levels of GDP, increases in HDI beyond the 4,000 kWh level are small.) At the low end of the electricity-use scale, of 27 countries with an HDI below 0.7, the annual per-capita electricity use in 24 is less than 1,000 kWh. Of 20 countries with an HDI below 0.6, annual per-capita electricity use is less than 1,000 kWh in 19.

[*] South Korea, Russia, Saudi Arabia, and South Africa.

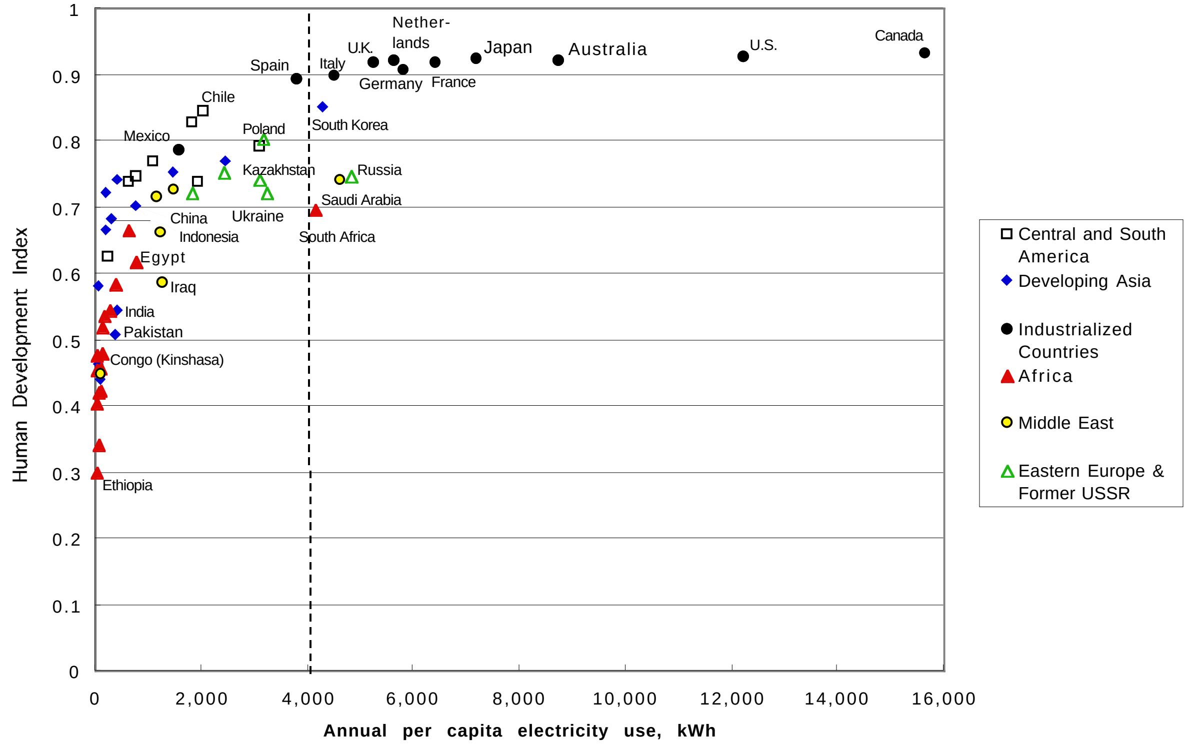

Figure 1. The United Nations' Human Development Index and electricity use. 60 Countries, 1997.
Sources: Human Development Report 1999, United Nations Development Programme, Table 1; International Net Electricity Consumption Information, Energy Information Administration, U.S. Department of Energy, <http://www.eia.doe.gov/pub/international/iealf/table62.xls>; International Data Base, U.S. Bureau of the Census, <http://www.census.gov/ipc/www/idprint.html>.

Data for 1980 show an HDI plateau somewhat less than 0.9 but an electricity threshold also at about 4,000 kWh per capita.[10] (See Figure C-1 in Appendix C.)

For 1997, the population distribution for the Human Development Index and for electricity consumption are shown in Figures 2 and 3 for the global 60-country sample by plotting cumulative population at or below the indicated values of HDI (Fig. 2) and annual per- capita electricity consumption (Fig. 3). In Figures 2 and 3, populations are shown in percent. In Figure 4, cumulative populations are plotted in absolute numbers against electricity consumption, and the area to the left of the curve is proportional to total annual electricity use in kWh. The two large population gaps in Figures 2, 3, and 4 represent the populations of India (0.9 billion) and China (1.2 billion).

As shown in Figure 2, only 14.6% of the sample global population enjoyed an HDI of 0.9 or greater in 1997. Figure 3 shows that 18.4% of the sample global population used 4,000 kWh or more of electricity. As reflected in Figure 4, this population subset accounted for 69.4% of the electricity used in the 60-nation sample. (See also Table 1.) Conversely, 66.2% of the sample population used less than 1,000 kWh per person per year and accounted for only 15.6% of the electric energy used. (Figures 3, 4, and Table 1.)

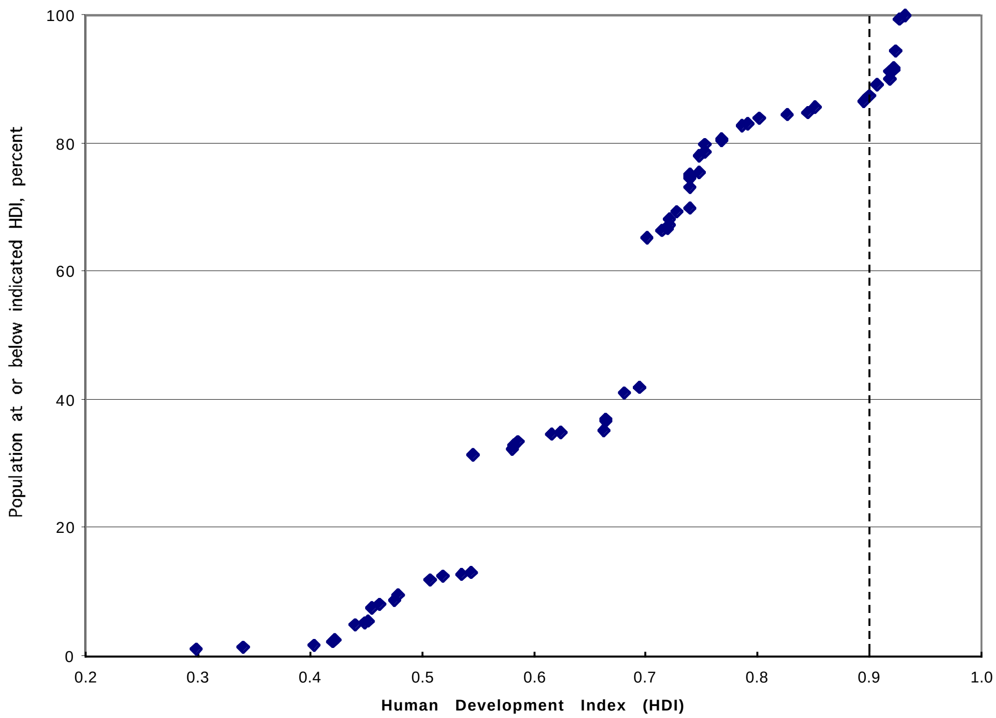

Figure 2. Population distribution of the United Nations' Human Development Index. 60 Countries, 1997.

Sources: Human Development Report 1999, United Nations Development Programme, Table 1; International Data Base, U.S. Bureau of the Census, <http://www.census.gov/ipc/www/idprint.html>.

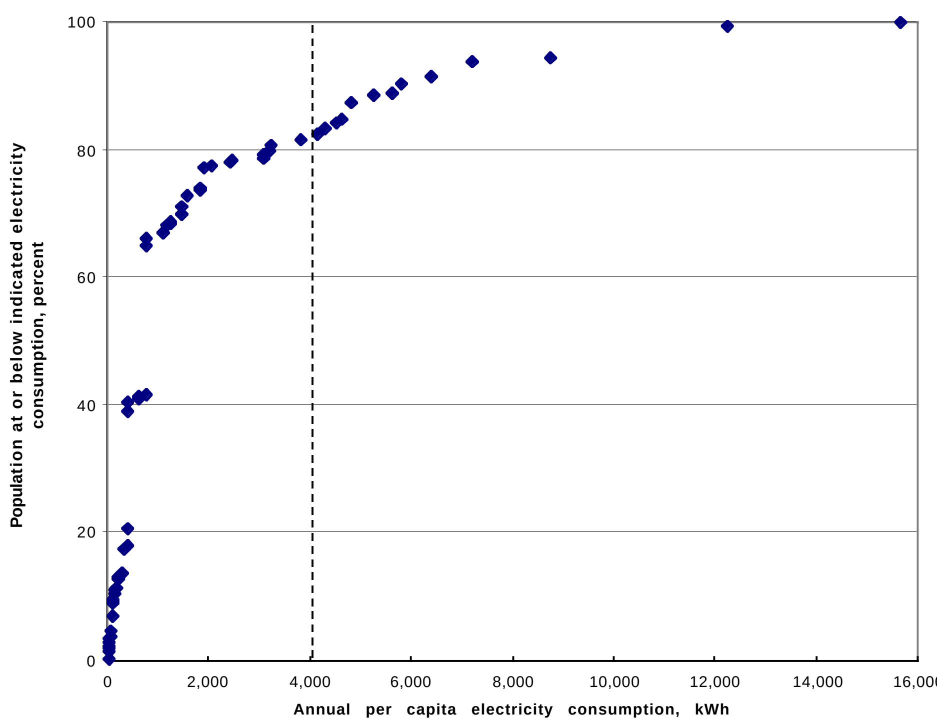

Figure 3. Population distribution of per capita electricity consumption. 60 Countries, 1997.

Sources: International Net Electricity Consumption Information, Energy Information Administration, U.S. Department of Energy, <http://www.eia.doe.gov/pub/international/iealf/table62.xls>; International Data Base, U.S. Bureau of the Census, <http://www.census.gov/ipc/www/idprint.html>.

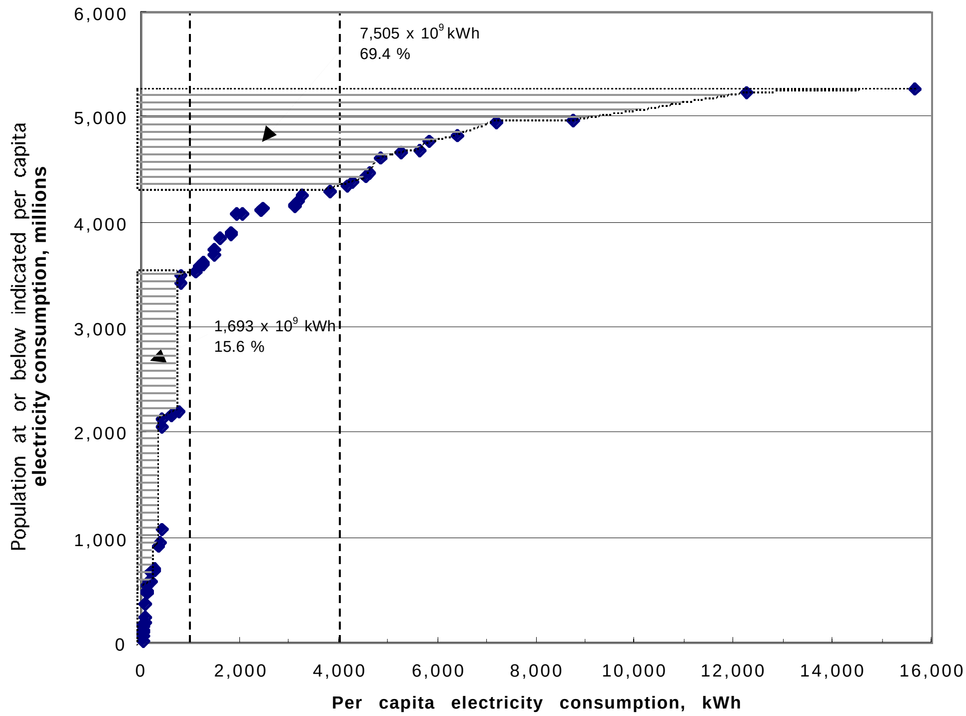

Figure 4. Population distribution of per capita electricity consumption. 60 Countries, 1997.
Sources: International Net Electricity Consumption Information, Energy Information Administration, U.S. Department of Energy, <http://www.eia.doe.gov/pub/international/iealf/table62.xls>; International Data Base, U.S. Bureau of the Census, <http://www.census.gov/ipc/www/idprint.html>.

One might also correlate the Human Development Index with total primary energy use and per-capita Gross Domestic Product (GDP). As demonstrated in Appendix B, the correlation of HDI with electricity is somewhat better than with total primary energy and displays a sharper threshold. It is at least as good as the correlation with GDP when HDI is modified by removing its GDP component so that a function containing GDP is not plotted against GDP. Of course, electricity use, energy use, and GDP are closely related.

Energy Intensity and Electricity Intensity

Figure 1 shows five countries with relatively low values of HDI, given that their per-capita consumption of electricity is close to or slightly above 4,000 kWh: Kazakhstan, Ukraine, South Africa, Saudi Arabia, and Russia. Perhaps the economies of these countries do not make an efficient conversion of electricity and energy to GDP. Energy intensity is a measure of how well energy is converted to income. As defined, low values are preferable. Here we define energy intensity as thousands of Btu per purchasing parity dollar (MBtu/PPP$). Similarly, electricity intensity is defined as kilowatt-hours per purchasing parity dollar (kWh/PPP$).

Of nine countries with an HDI of 0.9 or higher, the electricity intensity for eight is between 0.223 (Italy) and 0.433 kWh/PPP$ (Australia). The electricity intensity for Canada is higher at 0.697 kWh/PPP$.

Of the five countries with relatively low HDI values, three have high values of electricity intensity — i.e., they have relatively low incomes, as measured by GDP, given their consumption of electricity. They are Kazakhstan (electricity intensity = 0.869), Russia (electricity intensity = 1.107), and Ukraine (electricity intensity = 1.478 kWh/PPP$). But Saudi Arabia and South Africa have lower electricity intensities than Canada: 0.457 and 0.564 kWh/PPP$ respectively.

Although it is clear that a low value of electricity intensity is desirable (along with annual per-capita electricity consumption above 4,000 kWh), Saudi Arabia and South Africa appear to be exceptions. Annual per-capita electricity consumption for these countries is above 4,000 kWh, and they have better (i.e., lower) values of electricity intensity than Canada. Yet the HDIs for Saudi Arabia (0.740) and South Africa (0.695) are significantly lower than for other countries with similar levels of electricity consumption. The explanation for their relatively low indices of human development must lie elsewhere than in the efficiency with which they convert electricity to GDP.

Analysis based on energy intensity yields similar results. The nine countries with an HDI above 0.9 have energy intensities between 6.64 (Italy) and 17.88 MBtu/PPP$ (Canada). The energy intensities for Kazakhstan, Russia, and Ukraine are significantly higher at 33.2, 41.4, and 59.7 MBtu/PPP$ respectively. But compared to Canada, South Africa's energy intensity is slightly less at 13.8 MBtu/PPP$, while Saudi Arabia's energy intensity is only slightly higher at 20.6 MBtu/PPP$.

USDOE Projections of Energy and Electricity Use in Developed and Developing Countries

The U.S. Department of Energy's International Energy Outlook 1999 includes projections of energy and electricity production and consumption to 2020 for three economic growth cases: low, reference, and high.[11] Table 1 summarizes the information for electricity consumption by population at both the high and low ends of the electricity use spectrum. Figures 5 and 6 display the 1997 statistics and the 2020 projections over the entire spectrum of electricity use. As shown in Table 1, for both 1997 and the three projections for 2020, the percentage of the sample population at or above 4,000 kWh per person is small (about 18-24%), although some increase with high economic growth is evident. Comprising only one-fifth to one-fourth of the world's population, this sub-set of the global population accounts for about two-thirds of global electricity consumption in all four cases. Improvement at the low end of the scale, i.e., a decrease in the population using less than 1,000 kWh per person per year, is pronounced both with the passage of time and (especially) with high economic growth. This population decreases from 66% in 1997 to 26% in 2020 in the high economic growth case as India and China move above 1,000 kWh/capita of annual electricity use. (See Figures 5 and 6.)

Table 1. Global population (60-country sample) and DOE projections of electricity use.

	Above 4,000 kWh per Capita				Below 1,000 kWh per Capita			
	Population		Electricity Use		Population		Electricity Use	
Year/Case	10^6	%	10^9 kWh	%	10^6	%	10^9kWh	%
1997	970	18.4	7,505	69.4	3,490	66.2	1,693	15.6
DOE 2020 Low-Growth	1,178	17.4	10,125	63.0	3,294	48.6	1,472	9.2
DOE 2020 Reference	1,521	22.4	12,885	65.7	3,149	46.5	1,726	8.8
DOE 2020 High-Growth	1,638	24.1	15,740	66.4	1,763	26.0	625	2.6

Sources: Energy: DOE/EIA, International Energy Outlook 1999
Population: U.S. Census Bureau, International Data Base, http://www.census.gov/ipc/idbprint.html

However, in all three DOE projections for 2020, a large fraction of increased worldwide electricity use will occur in the 13 countries that are now (1997) above the 4,000-kWh-per-person threshold. These countries, with only 5.8% of the projected 60-nation sample population growth from 1997 to 2020, account for 36–39% of the projected growth in electric energy use in this period. When compared to the total global population, population growth in the 13 countries is 5.3%, and the growth in electric energy consumption is 33–36%.•

Figure 7 compares projections of electricity use in the DOE high economic growth case for 2020 with 1997 statistics and highlights the changes in annual electric energy consumption per capita and total electric energy consumption for the United States, China, India, Indonesia, and Vietnam.

Implications of the Annual 4,000 kWh per Person "Human Development Threshold" for Global Electricity Use in 1997 and 2020

A level of annual per-capita electric energy consumption of 4,000 kWh is only one-third that used in the United States and less than the average (5,500 kWh) for five populous Western European countries each, with an HDI above 0.9. (France, The Netherlands, Germany, the United Kingdom, and Italy.) Therefore, 4,000 kWh per-capita is a conservative standard, and its use can also be justified by the apparent "knee" at that level in the HDI vs. electricity consumption relationship.

• The 13 are Canada, the U.S., Australia, Japan, France, Germany, Netherlands, United Kingdom, Russia, Saudi Arabia, Italy, South Korea, and South Africa.

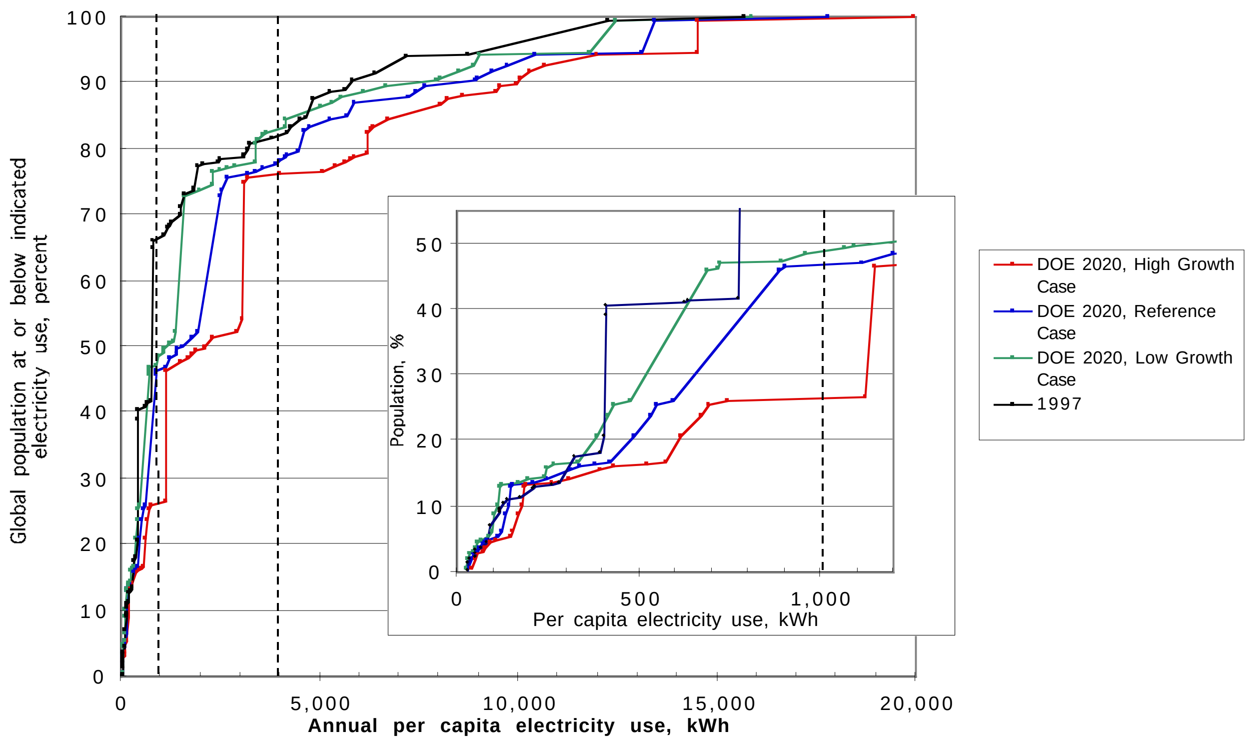

Figure 5. Global populations and per capita electricity use. 60 Countries: 1997 and projections for 2020.
Sources: International Energy Outlook with Projections to 2020, DOE/EIA-0484(99), (March 1999), U.S. Department of Energy; International Data Base, U.S. Bureau of the Census, <http://www.census.gov/ipc/www/idprint.html>.

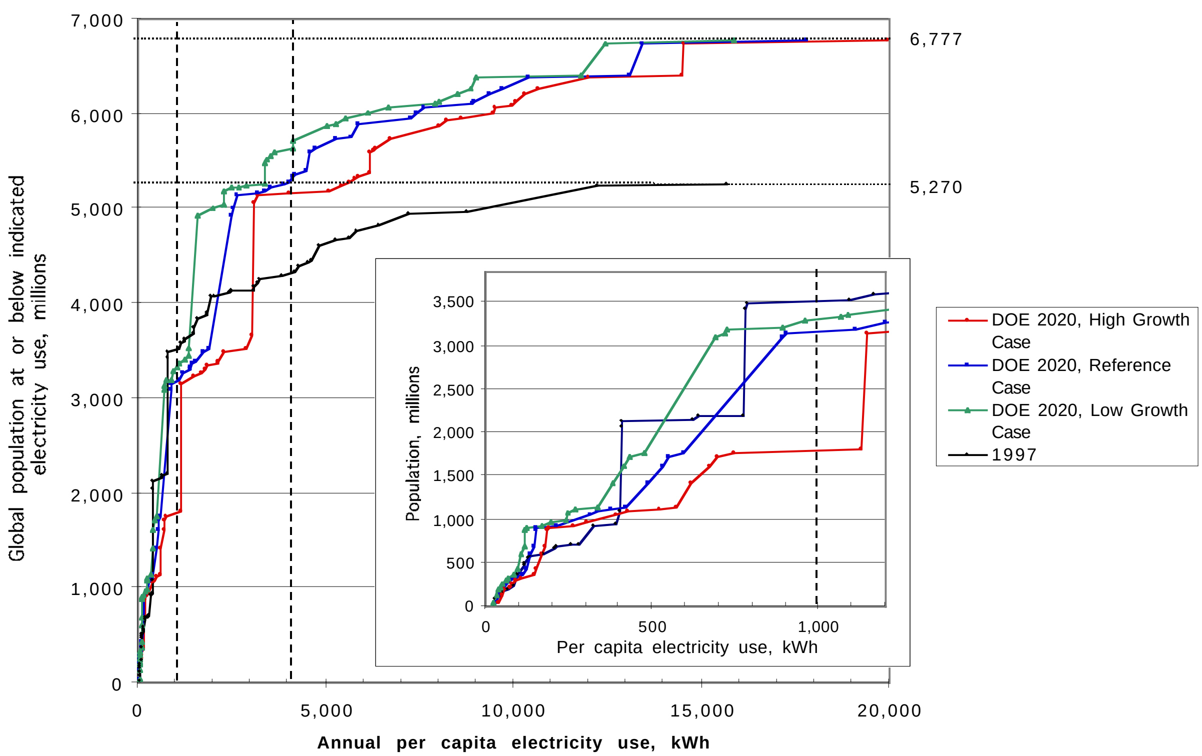

Figure 6. Global populations and per capita electricity use. 60 Countries: 1997 and projections for 2020.
Sources: International Energy Outlook with Projections to 2020, DOE/EIA-0484(99), (March 1999), U.S. Department of Energy; International Data Base, U.S. Bureau of the Census, <http://www.census.gov/ipc/www/idprint.html>.

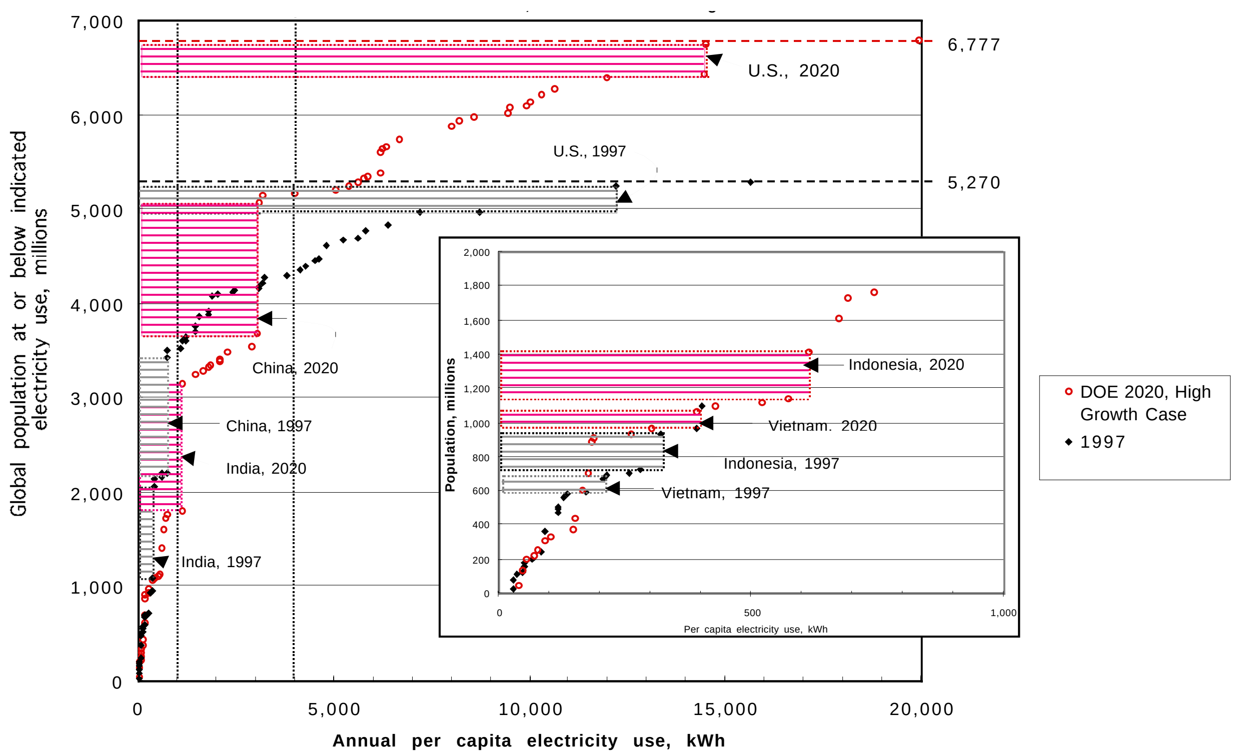

Figure 7. Global populations and per capita electricity use. 60 countries: 1997 and 2020 high growth projection.

Sources: International Energy Outlook with Projections to 2020, DOE/EIA-0484(99), (March 1999), Energy Information Administration, U.S. Department of Energy; International Data Base, U.S. Bureau of the Census, <http://www.census.gov/ipc/www/idprint.html>.

For each of the countries in which per-capita electricity consumption in 1997 is less than 4,000 kWh per year, the amount of additional electric energy required to bring consumption up to that level has been calculated based on country-by-country population and electricity use data.* For 1997, with the 60-country sample population of 5.3 billion people consuming 10,800 billion kWh, only 0.97 billion people (in 13 countries) are at or above annual electric energy consumption of 4,000 kWh per capita. To bring the remaining population up to this electricity threshold (overnight calculation) would require a minimum of an additional 13,900 billion kWh for a "global" (sample) total of 24,700 billion kWh, or about 2.3 times greater than 1997 consumption. For this calculation, the path of increasing global electric energy consumption as a function of population at or above 4,000 kWh per person per year is shown by the lowest curve in Figure 8.

* Population data for 1997 and projections for 2020 are from the U.S. Bureau of the Census.

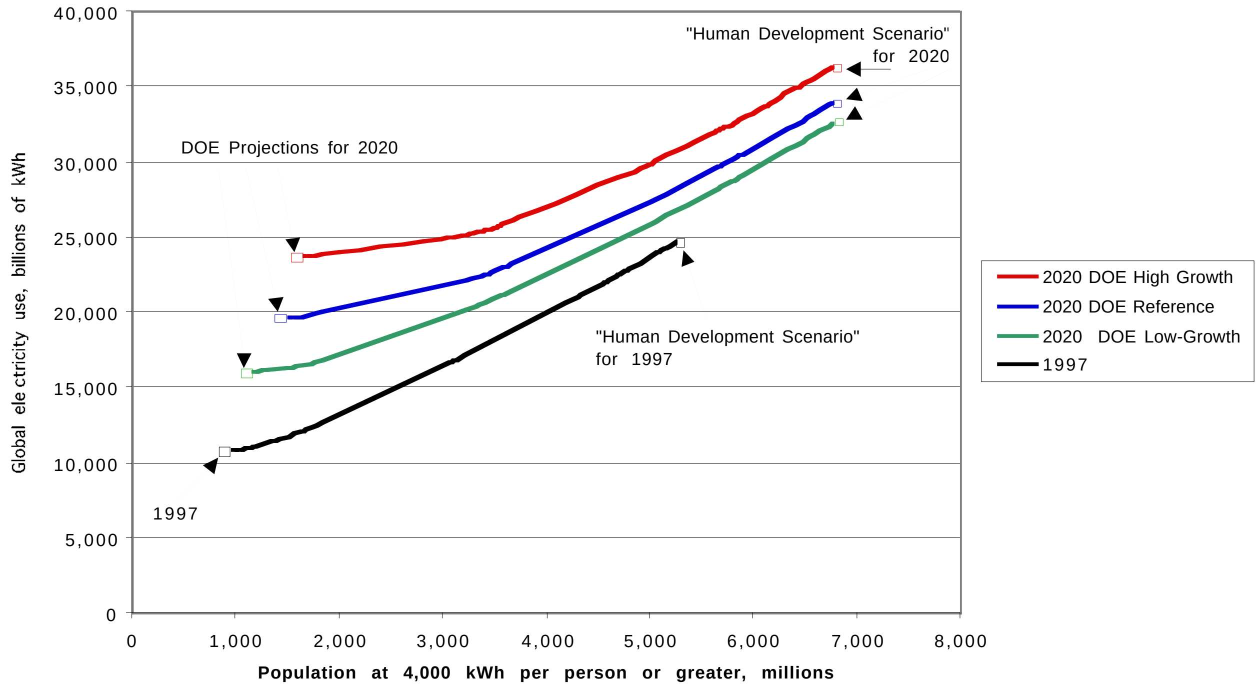

Figure 8. Global electricity use and population at or above 4,000 kWh per person per year. 60 Countries: 1997 and projections for 2020.

Sources: International Energy Outlook with Projections to 2020, DOE/EIA-0484(99), (March 1999), Energy Information Administration, U.S. Department of Energy; International Data Base, U.S. Bureau of the Census, <http://www.census.gov/ipc/www/idprint.html>.

Similar calculations can be made for the year 2020 incorporating population growth and the projected country-by-country distribution of electric energy use for each of the three DOE/EIA economic growth cases: low, reference, and high. Summing the country-by-country electric energy increments thus calculated provides an estimate of how much additional electric energy consumption in the 60-nation sample will be associated with an additional increment of population above the 4,000 kWh threshold. The results of these calculations are shown in Figure 8 as the top three curves. The curves are concave upwards, because the summation is performed so as to make the "most economical use" of the additional electricity increments. That is, each calculation starts by adding increments of electrical energy for those countries closest to the 4,000 kWh per-capita level and sequentially adding countries in descending order of projected per- capita electricity consumption (ascending order of additional needed per-capita electricity increments). In all calculations, the population projections are taken from the U.S. Census Bureau and are independent of projections of economic growth. The top three curves in Figure 8 reflect these calculations. In each case, the start of the curve (at the left) represents the projection of electricity use in the 60-country global sample as a function of the population at or above annual electric energy use of 4,000 kWh per capita based on the DOE projections. The ascending curve, for each growth case, represents the estimate of increased populations at the 4,000 kWh electric threshold as a function of increased electric energy use as the “human development electricity threshold” is approached, country-by-country, in the 60-country sample.

To summarize, the DOE projections for 2020 for the 60-country sample are 16,100, 19,600 and 23,700 billion kWh per year for the three cases representing ratios of 1.5, 1.8, and 2.2 times the 1997 electric energy consumption. The “human development” projections to bring the total 60-country “global” sample population to or above the electric energy threshold (the upper, right end of each curve) are 32,500, 33,900, and 36,300 billion kWh per year. These projections represent ratios of 3.0, 3.1, and 3.4 times the 1997 electric energy consumption level and are significantly greater than the ratios for the three DOE projections.

Implications for Total Primary Energy Consumption: The Ratio of Total Primary Energy to Electric Energy

For 1997, primary energy use is 337.6 quads in the 60-country sample and 379.5 quads for the world. (A quad is one quadrillion, or 10^{15}, Btu’s.) Consumption of electric energy for the sample is 10,820 billion kWh (36.9 quads) and 12,260 billion kWh (41.8 quads) for the world. The ratios of primary to electric energy consumption are, therefore, 9.14 for the sample and 9.07 for the world. (The closeness of these ratios provides added confidence that the sample is representative.)

In Figure 9, we observe that as economies use more electrical energy, the ratio of total primary energy use to electric energy use approaches a rough constant well under 10 and averaging roughly 7.5 at the high end. (As in the case of other correlations reported here, the fit is better when plotted against electric energy consumption than it is against total primary energy consumption.) At low values of energy per capita use, this ratio varies widely, from one country to another, from about 6 to over 25. [*] Some small countries with very high per-capita use of electricity have very low ratios. This is true for the Scandinavian countries. For example, annual per-capita electricity use in Norway, with 95% of its electricity generated by inexpensive hydropower, is about 24,000 kWh (twice the level in the U.S.), and the ratio of total energy to electric energy is only 4. In these countries, it is likely that electricity is used in applications, e.g., space heating, for which most of the United States would use natural gas. Also, the large component of hydro implies a lower ratio of primary to electric energy than is the case for economies more reliant on thermal generation of electricity. We can use the ratio to develop a conservative estimate for total primary energy use in the high-human-development projections for 2020.

[*] This may reflect inconsistencies in accounting for primary energy use such as unaccounted-for biomass use in developing countries.

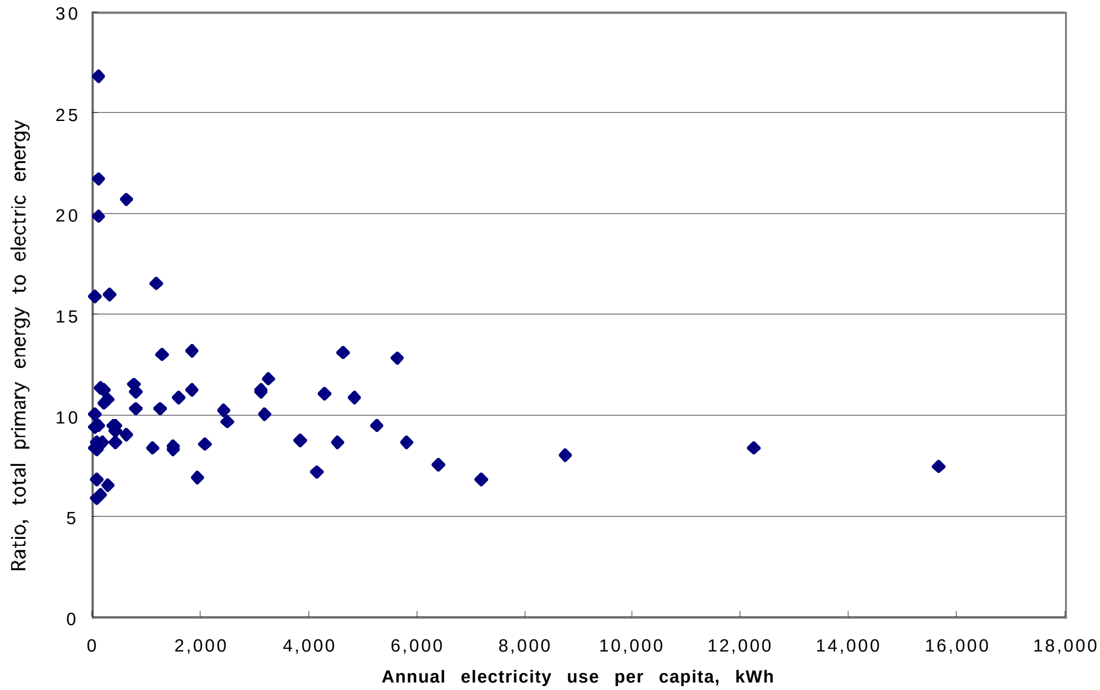

Figure 9. Ratio, total primary energy to electric energy and electric energy use. 60 countries, 1997.

Sources: International Net Electricity Consumption Information, Energy Information Administration, U.S. Department of Energy, <http://www.eia.doe.gov/pub/international/iealf/table62.xls>. International Primary Energy Consumption (Demand) Information, Energy Information Administration, U.S. Department of Energy, <http://www.eia.doe.gov/pub/international/iealf/tablee1.xls>.

As described above, Figure 8 shows projected electricity consumption for the 60-country sample according to DOE's low, reference, and high economic growth scenarios. Also shown are the results of country-by-country calculations in which an additional increment of electric energy consumption is added to the DOE projection (for countries below the 4,000-kWh-per-capita level) to bring the population to the 4,000 kWh per-capita threshold. The curve represents a running total of these added electricity and population increments. The uppermost point for each curve represents electric energy consumption in the 60-country sample when no country in the sample is below the 4,000 kWh per-capita threshold. These values are shown in Table 2 for the 60-country sample in billions of kilowatt-hours and quads for electric energy and in quads and exajoules for primary energy. To estimate total primary energy use, the projections for electricity are multiplied by 7.5. The estimates for global electric and primary energy consumption are simply 10/9 the values for the 60-country sample. (Entries in Table 2 are rounded to the nearest quad or EJ.)

Table 2. Electric energy and primary energy requirements in the human development scenario.

	60-Country Sample				Global			
	Electric Energy Use		Primary Energy Use		Electric Energy Use		Primary Energy Use	
Year/Case	10^9 kWh	Quads	Quads	EJ	10^9 kWh	Quads	Quads	EJ
1997	24,708	84	632	667	27,453	94	703	741
DOE 2020 Low Growth Case	32,521	111	832	878	36,134	123	925	976
DOE 2020 Reference Case	33,521	114	858	905	37,246	127	953	1,006
DOE 2020 High Growth Case	36,294	124	929	980	40,327	138	1,032	1,089

Comparison to Other Projections of Global Energy Use

The summary in Table 2 for the human development scenarios shows projected global electric energy consumption of about 36,000 to 40,000 billion kWh in 2020 and corresponding primary energy consumption of about 925 to 1,032 quads (976 to 1,089 exajoules). For electricity consumption, these estimates are about 52 to 102% higher than the DOE projections (102% for the low economic growth case and 52% for the high economic growth case). The corresponding increases in primary energy consumption are not quite as high, about 86% and 38%.

Steve Fetter[12] projects global primary energy use to 2100 and also reports projections by the Intergovernmental Panel on Climate Change, the International Institute of Applied Systems Analysis, the World Energy Council, and Shell Oil. For the year 2020, the range of 976 to 1,089 EJ/year estimated here for the human development scenario is about 65% higher than the projections reported by Fetter, which range from 500 to 750 EJ/year. In Figure 10, the Human Development Scenario high and low growth projections from Table 2 are superimposed on Fetter's projections as shown in Reference 11 (Fig. 4).

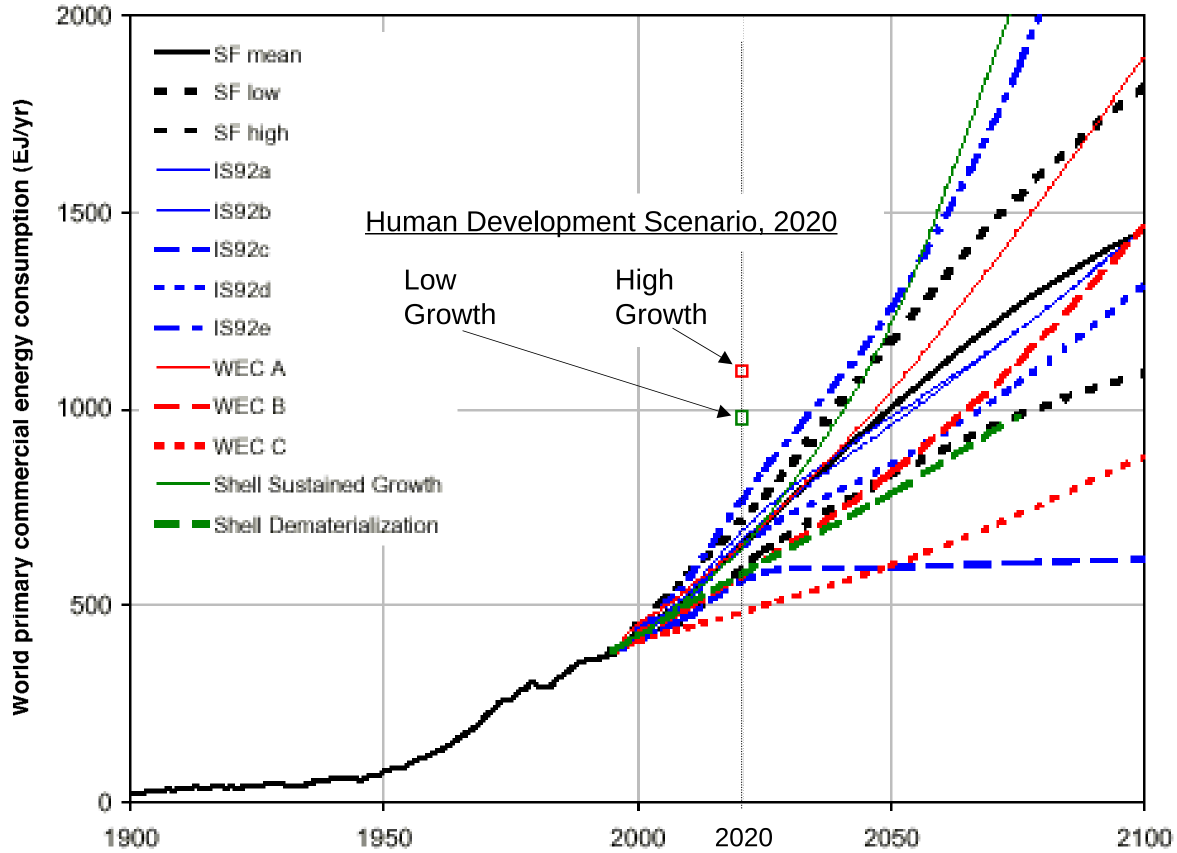

Figure 10. Global energy consumption, comparison of projections.
Source: Climate Change and the Transformation of World Energy Supply, Steve Fetter, Center for International Security and Cooperation, Stanford University, May 1999.

Conclusions

There is a significant association between electricity consumption and the United Nations' Human Development Index, a quantitative measure of human well-being. Of particular interest is an apparent threshold at an annual per-capita consumption level of 4,000 kWh. The threshold value permits an estimate of global electricity and energy consumption for a "human development scenario." This is not to imply that countries with higher levels of electricity consumption are wasteful. One would have to examine data for energy intensity (the ratio of energy consumption to GDP) and the structure of particular economies to make a determination on this point. Inter-country comparisons show that incomes rise with electricity use beyond the annual 4,000 kWh per-capita level. These additional incomes can contribute to higher standards of living. Our focus here is on basic indicators: life expectancy and educational attainment. What is of interest is the fact that large populations of the world are significantly below the electricity threshold level associated with a Human Development Index typical of developed countries. Their low HDIs reflect short life expectancy and low educational attainment — measures that are far more compelling than the purely economic metrics usually associated with energy consumption. Therefore, as noted by Rhodes and Beller, there is a compelling need for increased energy and electricity supplies in the developing countries.

In the past century, the government of the United States undertook large electrification projects to spur regional economic development and improve standards of living in this country: the Bonneville Power Administration, the Tennessee Valley Authority, and the Rural Electrification Administration. Annual per-capita electricity consumption in the United States reached 4,000 kWh in 1962.[13] According to current DOE projections, by 2020, 58 years later, 76% to 83% of the world's population will still be below this mark. (See Table 1 and Figure 5.)

The estimates of electricity use associated with high levels of human development presented in this analysis argue for substantially increased energy and electricity supplies in the developing countries and the formulation of supply scenarios that can deliver the needed energy within resource, capital, and environmental constraints. Neither the Human Development Index nor the Gross Domestic Product of developing countries will increase without an increase in electricity use. Considerations of interregional and intra-generational equity are as important as those of inter-generational equity.

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APPENDIX A

UNITED NATIONS' HUMAN DEVELOPMENT INDEX
AND HUMAN DEVELOPMENT INDICATORS, 1997

HDI	Life expectancy at birth (years)	Adult literacy rate (%)	Gross enrolment ratio* (%)	Real GDP per capita (PPP$)
High human development				
0.900–0.932	75.7–80.0	98.3–99.0	69–100	17,410–30,863
0.801–0.894	71.7–78.5	74.8–99.0	65– 92	6,520–28,460
Avg. 0.904	77.0	98.3	89	21,647
Medium human development				
0.506–0.797	44.1–75.7	40.9–99.0	37– 93	1,126–10,120
Avg. 0.662	66.6	75.9	64	3,327
Low human development				
0.254–0.491	37.2–60.7	14.3–77.0	12– 61	410–1,880
Avg. 0.416	50.6	48.5	39	982

* Combined first-, second-, and third-level gross enrolment ratio

APPENDIX B

Energy or Electricity?

HDI as a function of annual per-capita total primary energy use and annual per-capita electricity consumption is shown in Figures B-1and B-2 along with logarithmic trend lines. The fit is slightly better with electricity (Fig. B-1, R^2=0.84) than with total primary energy (Fig B-2, R^2=0.81). More significantly, the correlation with electricity shows a sharper threshold for attainment of an HDI of 0.9. The observation that HDI correlates somewhat better with electricity than with primary energy may reflect the facts that electricity is high-quality energy that can be used with high efficiency at the point of application and that electricity requires substantial infrastructure to generate, transmit, and use. It may also reflect the likelihood that data for electricity are more accurate than for primary energy.

The data sources for these figures are the United Nations' Human Development Report 1999 and the Energy Information Administration, U.S. Department of Energy.

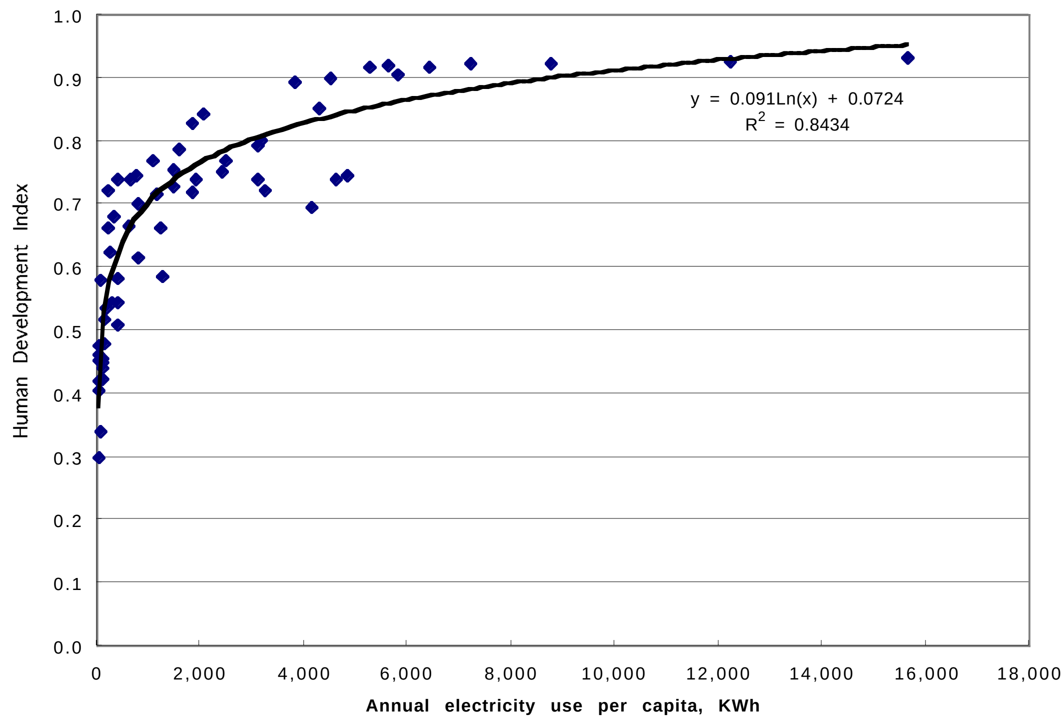

Figure B-1. Human Development Index and electricity use. 60 Countries, 1997.

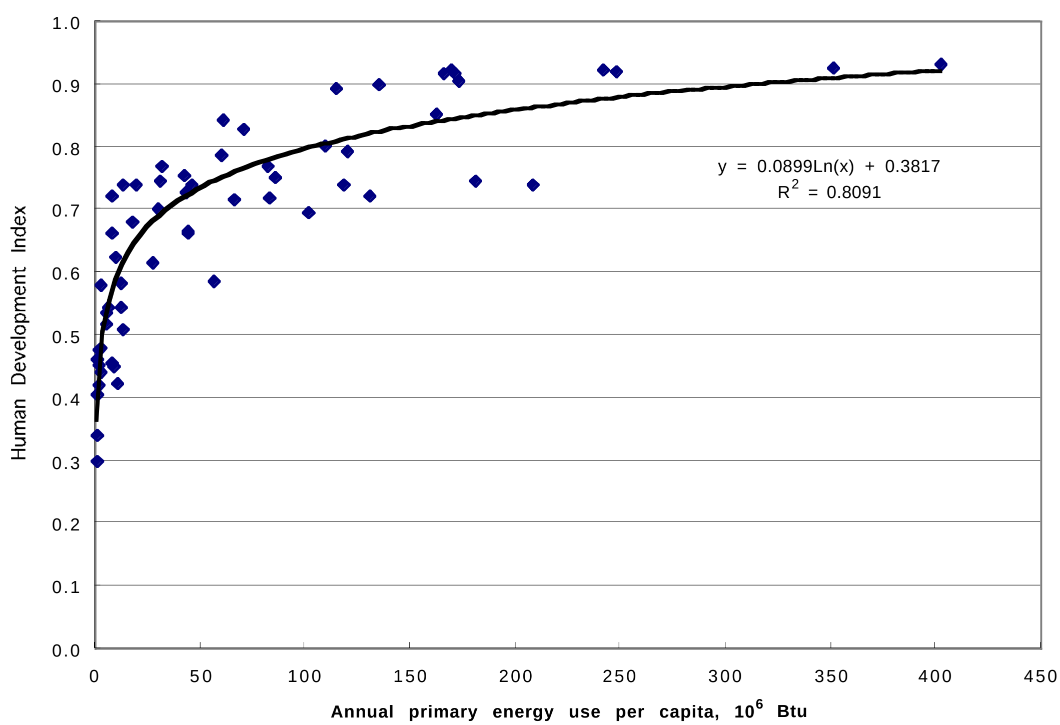

Figure B-2. Human Development Index and per capita total primary energy use. 60 Countries, 1997.

Electricity or Income?

In Figure B-3, HDI is plotted against real gross domestic product per capita in purchasing power parity dollars ($PPP). The fit is good ($R^2$=0.90) and is better than Figure B-1 (HDI v. per capita electricity consumption, R^2 = 0.84). However, this may be explained by the fact that the GDP index accounts for one-third of HDI. To that extent, GDP per capita is plotted against itself in Figure B-3. A better test is to remove the GDP index from HDI. The “Modified HDI” plotted in Figures B-4 through B-6 represents longevity and educational attainment in equal weights. Now the correlation with electric energy (Fig. B-4, R^2=0.79) is slightly better than the correlation with real per capita GDP (Fig. B-6, R^2=0.77) as well as the correlation with total energy (Fig. B-5, R^2 = 0.75). In Figure B-4, we observe the same threshold for HDI = 0.9 at 4,000 kWh per capita annual electricity consumption as in Figure 1.

The data sources for these figures are the United Nations’ Human Development Report 1999 and the Energy Information Administration, U.S. Department of Energy.

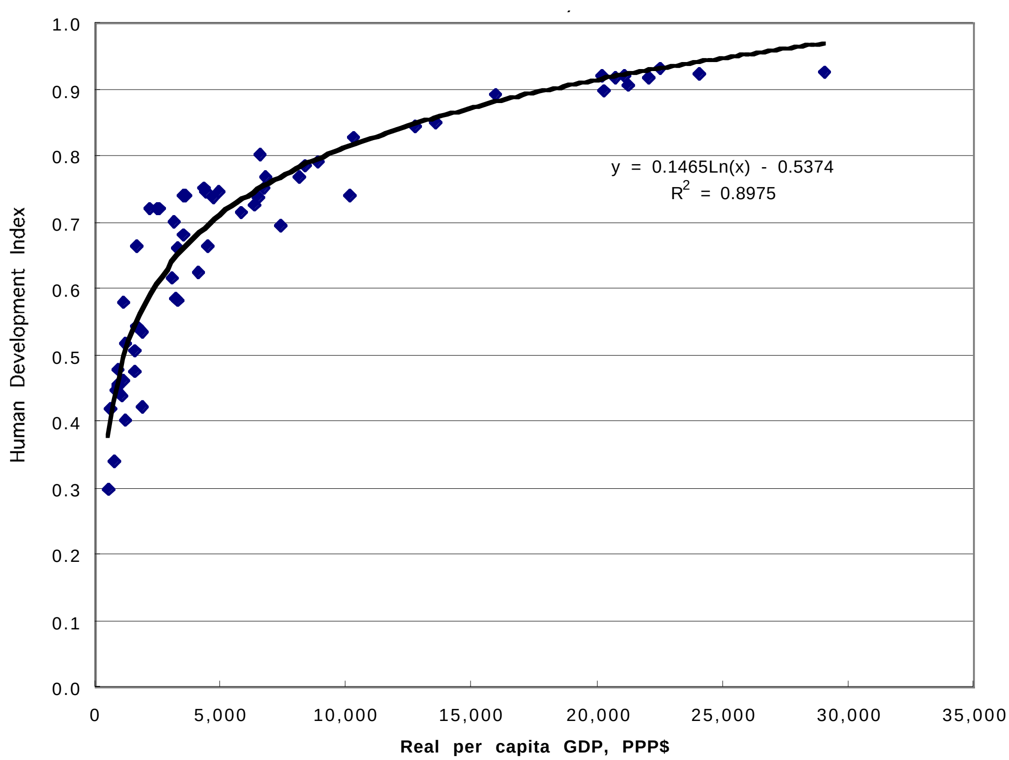

Figure B-3. Human Development Index and real per capita GDP. 60 Countries, 1997.

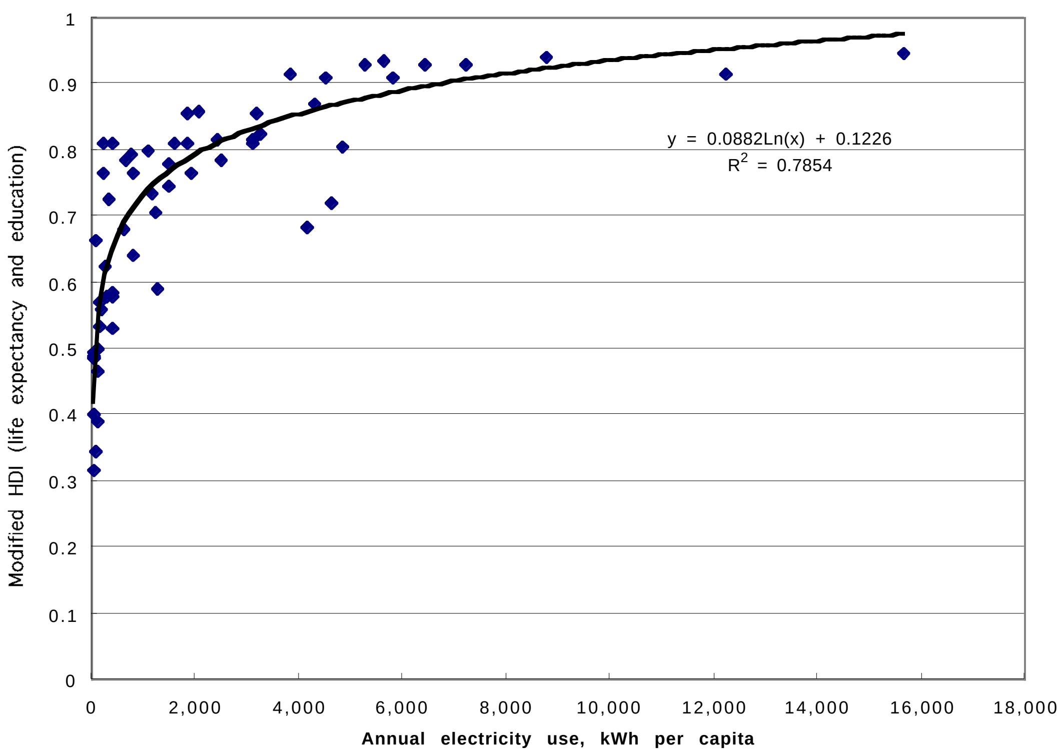

Figure B-4. Modified Human Development Index and per capita electricity use. 60 Countries, 1997.

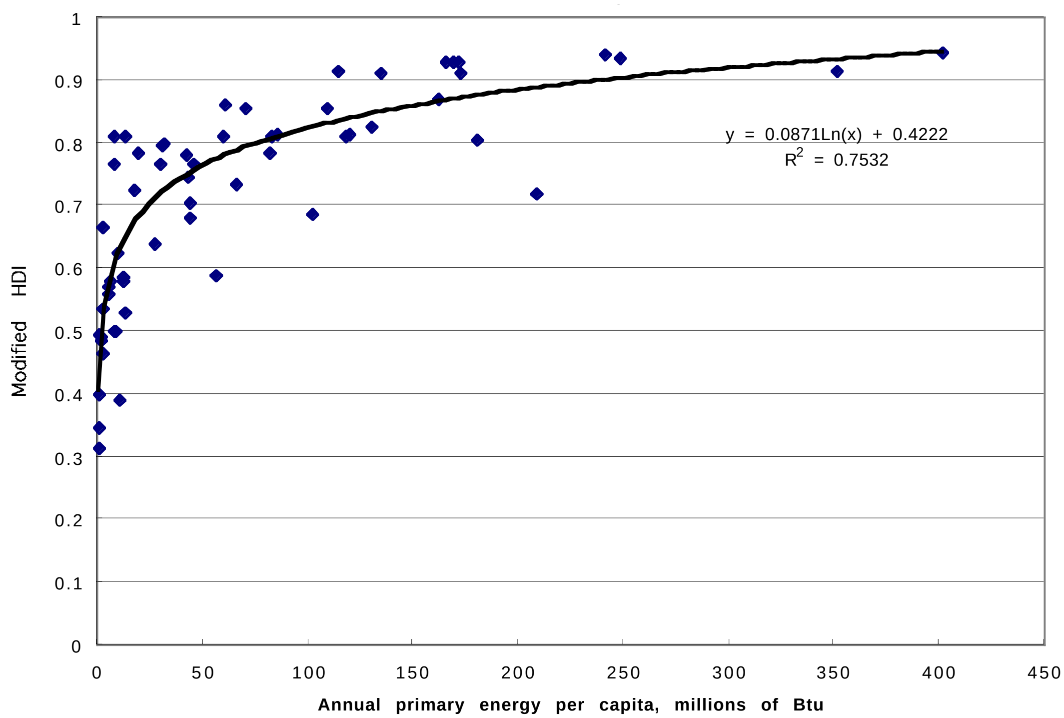

Figure B-5. Modified Human Development Index and per capita total primary energy use. 60 Countries, 1997.

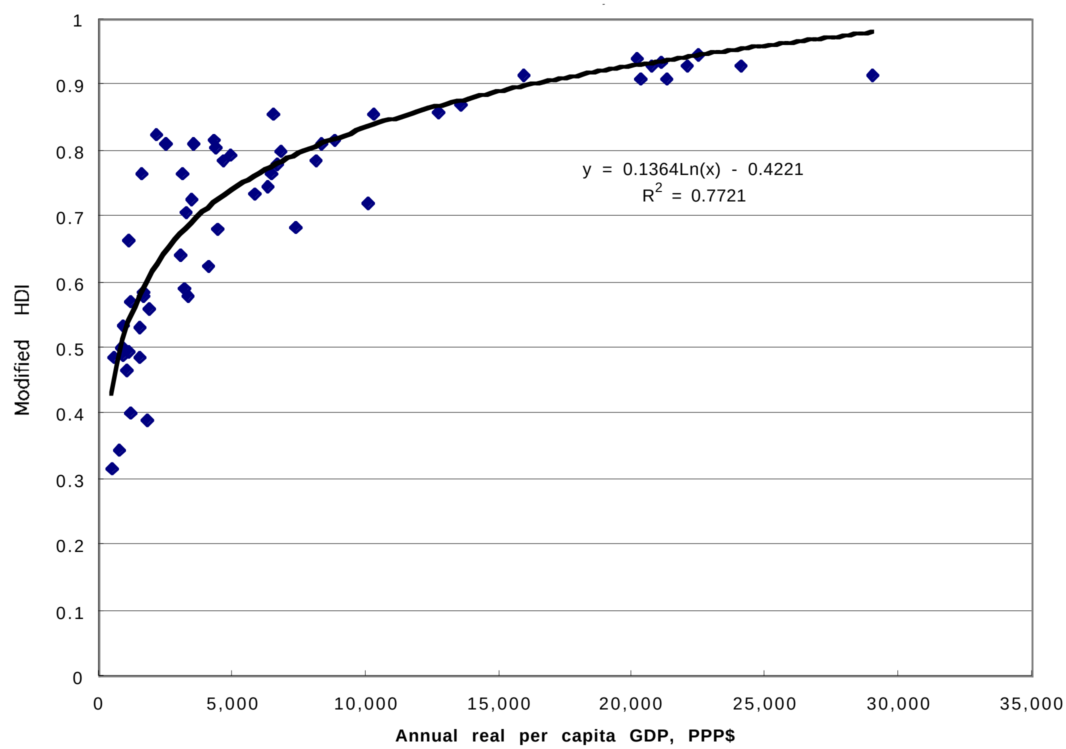

Figure B-6. Modified Human Development Index and real per capita GDP. 60 Countries, 1997.

APPENDIX C

Values of the Human Development Index for 1980 are plotted as a function of annual per capita electricity consumption in Figure C-1. This figure includes data for 73 countries comprising about 83% of the 1980 global population. The HDI plateau for 1980 is about 0.875, somewhat less than the 1997 value of about 0.925. However the 1980 plateau is reached at roughly the same value of 4,000 kWh per capita per year as found in 1997. So, while the maximum level of HDI has increased somewhat over the period from 1980 to 1997, the level of electricity consumption associated with maximum HDI has stayed about the same.

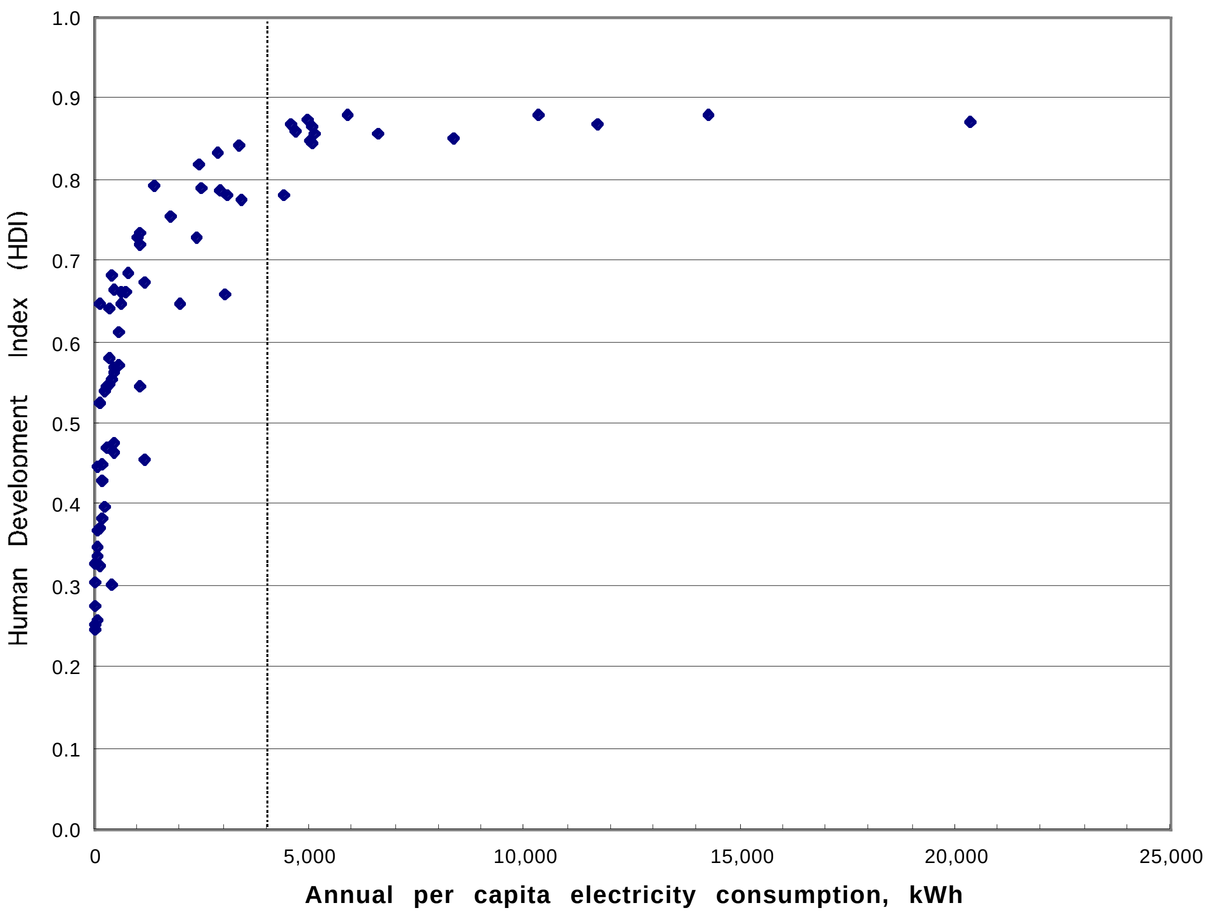

Figure C-1. The United Nations' Human Development Index and electricity use. 73 Countries, 1980.
Source: Human Development Report 2000, United Nations Development Programme, Tables 7 and 20.

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[11] Energy Information Administration, U.S. Department of Energy, International Energy Outlook 1999 With Projections to 2020, DOE/EIA-0484 (99), March 1999. Tables A1, A9, B1, B9, C1, and C9.
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