1. ENERGY AND HUMAN WELL-BEING

Human well-being is a difficult concept to quantify. Many attempts have been made in that direction the most obvious of them being the use of gross domestic product (GDP) per capita as an indicator. The shortcomings of such approach are well known and for this reason the HDI (Human Development Index) has been conceived as a composite of

- longevity – measured by life expectancy
- knowledge – measured by a combination of adult literacy (two-thirds weight) and mean years of schooling (one-third weight); and
- standard of living – measured by purchasing power, based on real GDP per capita adjusted for the local cost of living (purchasing power parity – PPP).

A rough idea of the relevance of energy to well being can be gained by plotting HDI as a function of per capita (commercial + non-commercial) energy consumption per year for a large number of countries, as shown in Figure 1.

Figure 1 HDI versus annual primary energy consumption (commercial + non-commercial per capita.

It is apparent from this figure that, for an energy consumption above 1 ton of oil equivalent (toe)/capita per year, the value of HDI is higher than 0.8 and essentially constant for all countries. One toe/capita/year[*] seems, therefore, the minimum energy needed to guarantee an acceptable level of living as measured by the HDI, despite many variations of consumption patterns and lifestyles across countries.

The statistical analysis presented above shows clearly that energy has a determinant influence on the HDI, particularly in the early stages of development in which are presently

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[*] 1 toe/year = 1.3kW

the vast majority of the world’s people, particularly women and children. It also shows that the influence of per capita energy consumption on the HDI begins to decline somewhere between 1 and 3 toe per inhabitant. Thereafter, even with a tripling in energy consumption, the HDI does not increase. Thus, from approximately 1 toe per capita, the strong positive covariance of energy consumption with HDI starts to diminish. Additional increases in HDI are more closely correlated to the other variables chosen to define it (life expectancy, educational level, and per capita income).

A serious problem with such analysis resides on the fact that commercial and non-commercial energy consumption are related in a complex way to the energy services that energy offers, which in households include illumination, cooked food, comfortable indoor temperatures, refrigeration and transportation. Energy services are also required for virtually every commercial and industrial activity. For instance, heating and cooling are needed for many industrial processes, motive power is needed for agriculture and electricity is needed for telecommunications and electronics.

The energy chain that delivers theses services begin with the collection or extraction of primary energy, that in one or several steps, maybe converted into energy carriers, such as electricity or diesel oil, that are suitable for end uses. Energy end-use equipment – stoves, light bulbs, vehicles, machinery – converts final energy into useful energy, which provides the desired benefits the energy services. An example of an energy chain – beginning with coal extraction from a mine (primary energy) and ending with produced steel as an energy service – is shown in figure 2.

Figure 2. An example of the energy chain, from primary energy to services

Energy services are the result of a combination of various technologies, infrastructure (capital), labor (know-how) materials and primary energy. Each of these inputs carries a price tag and they are partly substitutable for one another. From the consumer’s perspective, the important issues are the economic value or utility derived from the services. Consumers are often unaware of the upstream activities required to produce energy services.

Despite these caveats, the value of 1 toe/capita/year of primary energy consumption as an indicator of well being can be obtained less empirically using the Latin American World Model proposed by the Bariloche Foundation several decades ago.

The Bariloche study explores possible physical limits to establishing a society in which basic human needs are satisfied and, on the basis of a simple econometric model, investigates the possibility of doing so with current economic resources.

The target levels assumed in the Latin American World Model are:

- 3000 kcal and 100 grams of protein per person per day;
- one house (50 square meters of living area) per family; and
- 12 years of basic education (i.e., school enrolment of all children between 6 and 17 years).

The quantitative definition of a representative package of basic human needs is difficult for various reasons. For one, basic needs vary with climate, culture region, period in time, age and sex. For another, there is not a single level of basic needs but a hierarchy. There are needs, such as a minimum of food, shelter and protection from fatal diseases, that have to be met for survival. Satisfaction of higher-level needs such as basic education make productive survival possible. Top-level needs such as travel and leisure arise when people try to improve their quality of life beyond productive survival. Obviously, needs perceived as basic vary according to living conditions in any given society. Despite the difficulties involved in defining and ranking human needs, the three quantitative measures considered in the Latin American World Model may be regarded as a basic core for productive survival.

The final result of the Latin American World Model is the GNP per capita needed to satisfy basic human needs: this monetary income has been converted to commercial energy units using appropriate elasticity coefficients for the sectors considered. Thus the amount of commercial energy needed to satisfy basic human needs is obtained.

It is well known, however, that a large number of people in rural areas in developing countries do not have access to commercial energy due to lack of purchasing power or other reasons. These people depend for survival on non-commercial energy sources, principally firewood, dung and agricultural wastes, which they gather at a negligible monetary cost. In many developing countries, non-commercial energy accounts for a significant proportion of total primary energy consumption and 7.5 x 10^3 kcal/day per capita is considered to be a representative figure.

Adding this number to the cost of commercial energy to meet basic needs yields the total energy cost of satisfying basic human needs which, as shown in table 3.2, ranges between 27.8 x 10^3 and 36.4 x 10^3 kcal/day per capita, i.e., between 1.0 and 1.3 toe/capita.

Table I - Basic needs: per capita energy consumption

Region	Year	Commercial energy (kcal/day)	Non-commercial energy (kcal/day)	Total energy (kcal/day)
Latin America	1992	24.2 x 10^3	7.5 x 10^3	31.7 x 10^3
Africa	2008	20.3 x 10^3	7.5 x 10^3	27.8 x 10^3
Asia	2020	28.9 x 10^3	7.5 x 10^3	36.4 x 10^3

Source: Krugman, H and Goldemberg, J. “The Energy Cost of Satisfying Basic Human Needs” Technological Forecasting and Social Change, 24, 45-60 (1983).

Basic human needs might be met by a primary energy amount of approximately 1 toe/capita/year, but it is obvious that the idea of “well being” goes beyond that.

One very interesting study has tried to approach the problem starting from the assumption that the standard of living of the Western Europe, Japan, Australia and New Zealand in the mid 1970s could be considered satisfactory and the immense population living in developing countries would be very well off it had access to the services be available to the people of the above mentioned countries.

The activity levels in these countries in the mid 1970s are given in Appendix I and are basically the following:

- a renewable solid house with 25 m^2 per capita;
- water supplies and sanitation;
- clean easy-to-use cooking fuel (gas, for example);
- electrical lighting.

In other words, all families in the model above, on average, live in reasonably solid houses with about 25 m^2 per capita and water supplies and sanitation. Further, all homes would have a clean, easy-to-use cooking fuel (for example, gas), are illuminated with electric lights, and all the basic electric appliances – a refrigerator/freezer, a water heater, a clothes washer and a television set.

There is also one automobile for every 1.2 households on average, and the average person travels by air to the extent of 350 km per year. All this cannot be sustained without well-developed industries for the processing of basic materials and large services sector – hence, it is visualized that this infrastructure has been established and is in operation.

It is clear that these activity levels are more than sufficient to meet the basic needs of the population; in fact, they go very much farther to provide for major improvements in the quality of life.

Let's suppose now that most of these energy-utilizing technologies that are envisaged the above activities are example of the "best available" technologies in terms of their energy performance - for example, the most energy-efficient stoves, water-heaters, refrigerators/freezers, light bulbs, commercial buildings, cement plants, paper mills, nitrogen fertilizer plants. Because these technologies are available on the market they can be considered to be economically viable at present energy prices. A few of the indicated technologies are “advanced technologies” that could be commercialized over the next decade – hence, they are not contingent on the achievement of technological breakthroughs. Indications are that these technologies would be cost-effective at present energy prices.

One can then multiply each activity level by the corresponding specific energy demand, that is, the energy demand for unit level of the activity, and then sum up all the activities.

It turns out that, roughly speaking, the total final energy demand for the countries mentioned above, assumed activity levels and the menu of energy-efficient technologies is only about 1 toe per capita. This is both a surprising and remarkable result, because this level of final per capita energy use is only about 20 percent more than the actual per capita energy use rate in developing countries in 1980. The interesting implication of this result is that with 1 toe per capita of energy, developing countries can provide any standard of life ranging from the present low level (in which even basic human needs are not satisfied), to a level as high as in the Western Europe region in the mid and late 1970s for the majority of the population.

It is possible thus to achieve the large improvements in living standards without increasing energy use, in part because enormous increases in energy efficiency arise simply by shifting from traditional, inefficiently used, non-commercial fuels (which at present account for nearly half of all energy use in developing countries) to modern energy carriers (electricity, liquid and gaseous fuels, processed solid fuels, etc.).

The importance of the efficient use of primary energy use and the effect of modernizing energy supplies can be gauged by comparing direct energy use in rural and energy areas. An example is shown in Figure 3, which gives per capita energy consumption as a function with income in rural and urban area.

Figure 3 comparison of rural and urban per capita energy use in India versus per capita income

The somewhat surprising result is that the curve for rural areas is usually above the corresponding curve for urban areas. This means that, for any given income/expenditure, the per capita consumption of direct energy is higher in rural areas than in cities.

The reason for this result is simple: cooking is a major end-use of domestic energy in developing countries; the use of biomass, particularly fuelwood as a cooking fuel is far more common in rural areas; and this non-commercial energy is used at low efficiencies in fuelwood stoves. The tendency in cities is to shift to more efficient cooking fuels, often in this sequence: fuelwood to charcoal to kerosene to LPG. And the fuel efficiencies, with current technologies, are in the same sequence. Basically, the same type of effect takes place in the case of lighting too, because the percentage of kerosene-illuminated houses is higher in rural areas, and the tendency in cities is to shift to more efficient electric illumination. Thus, the lower urban energy consumption for a given income level corresponds to greater efficiencies and a better quality of life for urban households.

More generally speaking, the problem is evidenced by the way different energy sources are used as income increases in Brazil. As shown in Figure 4, households with low income rely almost entirely on fuelwood, which is used mainly for cooking in very inefficient cooking stoves. As income increases, “modern” fuels such as electricity and liquid fuels become dominant and higher income people not only have access to greater amounts of primary energy but also use them in more efficient ways. Typically, commercial energy is used with an efficiency of 25%, i.e., one quarter of the energy content of commercial energy is converted into electricity or mechanical power used by people. Non-commercial energy is commonly used for cooking with dismally low efficiencies around 10%.

Figure 4 Average energy demand by income segment in Brazil, 1988

Another positive impact of modernizing energy supplies and improving energy end-use efficiency is the reduction of the burden on women and children.

One can finally ask how good a measure of well being – as measured by HDI – is primary energy consumption

The response is given in Figure 5 where commercial plus non-commercial energy use are taken into account. What is shown is this figure is the difference in rank, Δ , between HDI and energy consumption. If $\Delta < 0$, the HDI rank is higher than the energy rank and if $\Delta > 0$ the opposite. As one can see, the correlation shows a considerable “variance” which indicates that energy “per se” is a poor indicator of human well being and that other factors such as climate, cultural patterns and living styles can be of considerable importance. This is particularly so in developing countries. In industrialized countries the correlation is better.

Figure 5 Energy use and HDI

2. HISTORICAL ACHIEVEMENTS AND LESSONS

The key to improving well-being without an inordinate increase in primary energy consumption is the modernization and increased end-use efficiency in the use of fuels, and transformation devices.

We will give here some examples of progresses achieved in the past.

A. Improvement of the Efficiency of the Use of Fuelwood

The basic problem of the use of fuelwood for cooking is its dismally low efficiency, which converts only about 10 per cent of the energy contained in the fuelwood into useful energy in the pot. Simple fireplaces are often dirty and dangerous: dirty because smoke and soot settles on utensils, walls, ceiling and people; dangerous because the fire is open and the pots can easily tip over. The smoke irritates and is a well-known danger to health.

With increasing affluence, people move from simple, primitive stoves using dung or crop residues, to wood or charcoal used in metal or insulated stoves, and finally to propane, liquid petroleum and electrical appliances, climbing an “energy ladder” which characterizes cooking (Figure 6)

Figure 6 Efficiency of stoves with commercial and non-commercial fuels

Moving up the “ladder”, improvement in pollution reduction is dramatic: a gas stove emits 50 times less pollutants and is 5 times more efficient than a primitive stove. With higher efficiencies, capital costs also increase, posing severe problems for the very poor. This is, however, the direction in which to move a large number of programs in Africa, Asia and Central America that have been successful in disseminating many millions of more efficient stoves used in rural areas and cities.

Experience has shown that very simple improvements to primitive cooking stoves cost little and can improve their efficiency considerably. This is particularly the case for the Kenya Ceramic Jiko (KCJ) stove, 700,000 of which are in use today in East Africa, as well as some of its variants. Over 13,000 KCJ stoves are sold in Kenya each month.

Improvement of fuelwood cookstove programs succeeded in China, but not so well in India. Jiko stoves, so successful in Kenya, did not fare well in Rwanda. The reason why programs for dissemination of better stoves succeed in some countries and not in others is difficult to understand, but seems to depend heavily on education and grassroot involvement rather than government action alone.

The prospect for women’s education improves as the drudgery of their household chores is reduced with the availability of efficient energy sources and devices for cooking and of energy-utilizing technologies for the supply of water for domestic uses. The deployment of energy for industries, which generate employment and income for women, can also help delay the marriage age, another important determinant of fertility. If the use of energy results in child-labour becoming unnecessary for crucial household tasks, an important rationale for large families is eliminated. Thus, energy can contribute to a reduction in the rate of population growth if it is directed preferentially towards the needs of women, households and a healthy environment.

B. Mechanical power (from oxen to steam engine)

Table II gives an idea of chronological advances in power output available to men since 3000 BC.

Table II Chronological advances in power output

Primer mover	**Date**	**Output in horsepower (HP)**
Man pushing a lever	3000 BC	0.05
Ox pulling a load	3000 BC	0.5
Water turbine	1000 BC	0.4
Vertical waterwheel	350 BC	3
Turret windmill	1600 AD	14
Savery’s steam pump	1697 AD	1
Newcommen’s steam engine	1712 AD	5.5
Watt’s steam engine (land)	1800 AD	40
Steam engine (marine)	1837 AD	750
Steam engine (marine)	1843 AD	1,500
Water turbine	1854 AD	800
Steam engine (marine)	1900 AD	8,000
Steam engine (land)	1900 AD	12,000
Steam turbine	1906 AD	17,500
Steam turbine	1921 AD	40,000
Steam turbine	1943 AD	288,0001,
Coal-fired steam power plant	1973 AD	1,465,000
Nuclear power plant	1974 AD	1,520,000

Source: Cook, E, Man, Energy, Society, WH Freeman and Co, San Francisco, US (1976).

The greatest advance was the steam engine developed by Watt, which opened the way for an extraordinary increase in the efficiency of the energy contained in coal (or other fuels) to mechanical power through a steam engine cycle. Figure 7 shows typical improvements in efficiency since watt’s initial device.

Figure 7 Efficiencies of steam engines

C. Improvements in electrical end-use devices

In the present century, we have wittnessed the emergence of refrigerators freezers, air–conditioner, washing machines, and other domestics appliances which have improved enormously the well-being of people, particularly relieving women from heavy domestics chores.

One can obtain an idea of the typical progresses achieved in this area in Figure 8, which gives the evolution in refrigerators' consumption of a typical 200 liter refrigerator with no freezer compartment. A reduction of a factor of 5 was obtained between 1973 and 1988 and further progress achieved since them. in refrigerators' electricity consumption.

Figure 8 Efficiency of refrigerators

D. Improvements in lighting

More spectacular have been advances in obtaining lighting from electrical lamps. Since the former days of Edison, some 100 years ago with incandescent filaments (wich produced more heat than light), enormous progress was achieved and gains of a factor of 100 in lumens/watt obtained, as shown in figure 9.

Figure 9 Efficiency of lighting

3. THE HUMAN DEVELOPMENT INDEX AND THE USE OF ENERGY

Even if energy is a poor indicator of human well-being and other factors can be of considerable importance, there are some relevant correlations between the use of energy and the HDI rank. Thus, considering the HDI rank and comparing the highest 10 HDI countries to the lowest 10 HDI countries, some important features become apparent in the use of energy by each group of countries:

- the share of commercial energy vs. traditional fuels;
- the path of energy intensity;
- the access to energy saving technologies.

10 highest HDI rank

Canada
France
Norway
United States
Finland
Iceland
Japan
New Zealand
Sweden
Spain
Austria
Belgium

10 lowest HDI rank

Uganda
Malawi
Djibouti
Guinea-Bissau
Gambia
Guinea
Burundi
Mali
Burkina Faso

The use of commercial or traditional fuels is a distinguishable feature for its place in the HDI ranking. Highest HDI countries use commercial energy, while lowest HDI countries consume traditional fuels. As shown in figure 10, the share of commercial energy is in the range of 97-100% in the 10 highest HDI countries and are in the range of 10-20% for most of the 10 lowest HDI countries.

Figure 10 HDI and energy use

The evolution in energy intensity in the period 1970-1995 shows the 10 highest HDI countries following a decreasing path and the 10 lowest HDI countries in an increasing path. Moreover, while the 10 highest HDI countries were successful decoupling energy consumption and development, the 10 lowest HDI countries use more energy per GDP-PPP unit using traditional fuels. Energy intensities for the 10 lowest HDI countries were considered for the period 1973-1985 due to lack of consistency in data for the year 1995. Figure 11 shows the energy intensity paths followed by the two group of countries.

Figure 11 Energy intensity

One major feature of the 10 lowest HDI countries is the use of traditional fuels as shown in Table II.

Table II – Share of traditional fuels in lowest HDI countries

HDI value	Country	1973	1985
0.340	Uganda	83%	92%
0.334	Malawi	87%	94%
0.295	Guinea-Bissau	72%	67%
0.291	Gâmbia	89%	78%
0.277	Guinea	69%	72%
0.241	Burundi	97%	95%
0.236	Mali	90%	88%
0.219	Burkina Faso	96%	92%

Sources: World Resources Institute (for traditional fuels); Human Development Report 1998.

The 10 highest HDI rank countries have each an efficient energy system. Such a system was built through large investments in infrastructure and system components aiming at reducing the energy use costs and improving the overall performance. Each of these countries adopted energy efficiency measures through policies and programs, mainly since the first oil shock (1973-1974). The evolution of energy use in some of the highest HDI rank countries is shown in Figure 12, stressing the decoupling between energy consumption and economic development.

Figure 12 Decoupling of energy consumption and economic development in highest HDI rank countries

4. THE CONVERGENCE OF ENERGY CONSUMPTION PATTERNS BETWEEN INDUSTRIALIZED AND DEVELOPMENT COUNTRIES

The evolution of the energy intensity is a useful reference to set up the path of improvements or losses in the efficient use of energy. Moreover, for each country, it can indicate changes in the economic structure and in the fuel mix. Energy intensity is the ratio of total primary energy supply to GDP.

Important commonalities exist among the energy systems of rather different countries, since energy use (E) and GDP per capita vary by more than order of magnitude when comparing developing to industrialized countries, while energy intensity does not change by more than a factor of 2. In addition, for developing countries are concerned, this probably reflects the fact that “modern sector” of the economy dominates both E and GDP, while the “traditional sector” contributes little to both.

Energy intensity (considering only commercial energy sources) declined in OECD countries in the period 1971-1991 at a rate of roughly 1.4% per year. The main reasons for that movement were efficiency improvements, structural change and fuel substitution. However, in the developing countries the pattern has been more varied.

The measure of the economic development usually employs market exchange rates to convert each country's GDP in U.S. dollars. In fact, the market exchange rate for a currency often does not reflect that currency's true purchasing power at home. A major innovation has been the introduction of U.S. dollars using purchasing power parities (PPP) to measure the GDP. The use of PPP-converted GDP made possible to determine a common "market basket" of goods and services each currency can purchase locally, including goods and services that are not traded internationally. In fact, from a PPP perspective, the developing world's share of economic activity is large than is reflected in market-based exchange rates.

A recent study indicates that the energy intensity in the period 1971-1992 of developing and industrialized countries is converging to a common pattern of energy use. For each country, energy intensity was obtained as the ratio of commercial energy use to GDP converted in terms of purchasing power parity (PPP). The path of energy intensity of a country was given by the yearly sequence of energy intensity data over the period 1971-1994. The same procedure was followed to have the energy intensity paths for a set of 18 industrialized countries and for one of 23 developing countries. The energy intensity data for each of these subsets were given by the ratio of total commercial energy use to total PPP-converted GDP for each group of countries at each year of the period 1971-1994 (Figure 10)

Figure 13 Energy Use/GDP

Energy use data for the 41 countries were gathered at the World Bank's World Development Indicators tables at the commercial energy use series over the period 1971-1992 and given in 1000 t of oil equivalent. The PPP-converted GDP data for the 41 countries over the period 1971-1992 were obtained from the World Resource Institute based on the Penn World Tables (PWT) and the World Bank's World Development Indicators. PPP-converted GDP data were initially obtained in current International currency. Current data were, then, converted into constant (1992 US dollars) applying the

GDP implicit price deflator published by the US Department of Commerce, Bureau of Economic Analysis (Survey of Current Business, July 1998).