Energy Use in Rural India

It is surpisingly high, but an increase in energy supplies and more efficient utilization are needed.

Roger Revelle

The economic chasm that divides the world also separates two vastly different levels and kinds of energy use. More than five-sixths of all the energy obtained from fossil fuels and hydroelectric and nuclear power is used by the billion inhabitants of the rich countries and less than one-sixth by the 3 billion people of the poor countries (*1, 2*). The reverse is true of the traditional sources of energy—human and animal labor, firewood, crop residues, and animal wastes—that were predominant throughout history everywhere until the last two centuries. The total quantities of energy from these sources used in the poor countries today are probably about equal to their consumption of fossil fuels, and greatly exceed the uses in the rich countries.

International statistics on energy use are usually based only on consumption of "commercial" energy and hence seriously underestimate total energy consumption in poor countries. In India, for example, energy use per capita is generally given the U.N. coal equivalent (*3*) of 150 to 190 kg (*1, 2*), whereas, as we shall see, total energy use from all sources is close to 490 kg. In the rural areas of poor countries, energy provided by the people themselves is five to ten times that obtained from commercial sources. Nevertheless, usable energy is in very short supply, and the needs both for a large increase in supply and for conservation through more efficient utilization are great.

From an energy standpoint, rural India can be thought of as a partially closed ecosystem in which energy derived by people and animals from the photosynthetic products of plants is used to grow and prepare human food, which in turn provides an essential energy input to grow more food, and so on in an endless cycle. The ecosystem is being disrupted by rapid population growth.

The author is professor of population policy at the Harvard University Center for Population Studies, Cambridge, Massachusetts 02138 and professor of science and public policy at the University of California, San Diego, La Jolla 92093.

Estimation of Human Energy

Several different methods have been employed to compute the human and animal energy used in work.

Pimentel *et al.* (*4*) take the total food energy input of a full-time farm worker (working 40 hours per week) as a measure of the energy utilized in farm labor. For example, they show that 9 hours of labor per acre are used in U.S. corn production, and they calculate the energy input as 9/40 multiplied by the energy in 1 week's food consumption (assumed to be 21,770 kcal), or 4900 kcal per acre.

Makhijani and Poole (*5*) use the energy in the food intake of all persons in a farming village as the gross energy input for human labor. They give a hypothetical example of a village of 1000 people consuming on the average 2000 kcal per day per capita in food, with a gross energy input of 7.3×10^8 kcal per year or 0.73×10^6 kcal per person. The annual work output per capita from persons more than 15 years of age, taken as half the total population of the village, is assumed to be 0.045×10^6 kcal, giving an "energetic efficiency" of 3 percent for all human beings in the village.

Passmore and Durnin (*6*) and White *et al.* (*7*) estimate the metabolic energy used in different work activities from measurements of oxygen consumed or carbon dioxide exhaled. East African women, obtaining water for household use by walking to a well or water hole and carrying the water home in jars on their heads, expend on the average 240 kcal each day and take 46 minutes for the task (*7*). In unmechanized agriculture in Hungary, Russia, Italy, Germany, and Gambia, 19 groups of men, with a mean weight of about 65 kg, expended on the average 6.0 kcal per minute in a variety of agricultural tasks. Fourteen groups of women in Russia, Italy, Gambia, and Nigeria, with a mean weight of about 55 kg, expended on the average about 4.7 kcal per minute (*6*).

The average daily or weekly energy expenditures in most working activities are less than the measured values for particular tasks. A British miner, working a 44-hour week, was observed to expend an average of 269 kcal per hour during working hours, or 4.5 kcal per minute, even though the average energy expenditure for different mining tasks is 6.7 kcal per minute (*6*). Approximately one-third of his working time was spent in rest. Even so, the weekly energy expenditure of this miner during working hours was nearly 45 percent of his total food energy intake for the week.

The different methods of estimating energy expenditure are compared in Table 1 in terms of an average Indian rural worker (50 percent of the rural population), who is assumed to work 1800 hours per year. Obviously the method of Passmore and Durnin (*6*) and White *et al.* (*7*) gives the lowest values for yearly energy in work by human beings, particularly for a rural population, such as India's, in which there is considerable underemployment. This method is used in Table 2 to estimate energy expenditures for human labor in rural India.

From Table 2 we see that somewhat more than half of the estimated 500 billion hours per year of human labor are spent directly in agriculture. Cooking, obtaining water, collecting fuel, and other domestic activities take up nearly 200 billion hours, or 39.5 percent of the total hours worked, and all other occupations take up slightly more than 9 percent. Human energy expended in agricultural work is estimated to be 55 percent of the annual total of 1.08×10^{14} kcal (120 billion kwh) expended in all labor.

Approximately a third of the food energy consumed by the rural population (*8*) is used in work (Table 3). If our figures are correct, women and girls work harder than men and boys, in terms of the proportion of food energy expended in labor. Women 15 or more years old use 44 percent of their energy intake in labor, while males in this age group use 38 percent. It would appear that adult women work about as hard as the British coal miner described above (*6*).

The estimate of the total number of hours worked in agriculture computed from Table 2 is in fair agreement with observations in a World Bank study of cereal production in Bangladesh (*9*). The number of man-days of labor ranged from 125 per hectare in wheat production to 150 per hectare in broadcast aus and aman (monsoon) rice, 175 days in transplanted aus and mixed aus and aman, and 218 days in boro (winter) rice. Since about 80 percent of the 163 million gross sown hectares in India is planted to food grains (cereals and pulses), of which about 30 percent is in rice, 15 percent in wheat, and 35 percent in other cereals and in pulses (*10*), it can be assumed that the World Bank figures apply fairly well to Indian agriculture. Taking a rough average of 150 man-days per hectare, and assuming an average working day of 10 hours, a total of 245 billion hours of labor would be spent directly in agriculture. The total from Table 2 is 255 billion.

Animal Energy

It is less easy to determine the proper way to account for energy expended in bullock work, and the underlying data are less adequate. If a bullock can be thought of as a kind of working machine, then the energy in its "manufacture" might be included in the accounting—that is, the net energy input (feed energy minus energy in dung) of the entire cattle population, less the energy in milk and other products. Alternatively, the energy consumed annually in feed by the bullock itself, minus the energy in its dung, divided by the number of hours worked, could be taken as its gross energy expenditure per working hour. I have used a third method, which gives smaller values, assuming that a fully employed bullock, like a human manual worker, utilizes about 43 percent of the energy it consumes in work.

The first method is essentially that used by Odend'hal (*11*) for the cattle population of a village in West Bengal (*12*). Subtracting the energy in dung and milk produced by this population of 3770 animals from the energy in feed consumed, and dividing by 1079, the number of working bullocks, gives an annual energy input per bullock of 14.5×10^6 kcal, or dividing by 1200 hours of work per year, 12.1×10^3 kcal per hour of work. This number should be reduced because not all the male calves produced in the herd are retained by the villagers, and the gross energy expenditure in the herd's milk production (probably between five and ten times the energy in the milk) has not been considered. The energy in milk was 1.83×10^8 kcal per year, and if the gross energy expenditure in milk production was 1.83×10^9 kcal per year, the gross energy input per bullock hour worked was less than 10.9×10^3 kcal.

With Odend'hal's data, the second method gives 5.3×10^3 kcal per hour, and the third 2.3×10^3 kcal per hour,

Table 1. Comparison of methods of measuring human energy expenditures in agriculture.

Method	Energy per worker (kcal/hour) Gross input (expenditure)	Energy per worker (kcal/hour) Useful output
Pimentel *et al.* (*4*)	580*	
Makhijani and Poole (*5*)	870*	25
Passmore and Durnin (*6*)	250†	

*The energy in weekly food intake is 20,200 kcal per adult male and 15,050 kcal per person for the entire population (see Table 3). †The average energy expenditure during work is assumed to be 70 percent of the energy used in specific agricultural tasks.

compared with an output of useful work of 0.43×10^3 kcal per hour (*11, 12*), corresponding for the third method to an "energetic efficiency" of about 19 percent. The 1971 population of bullocks in India was 70.4 million (*13*), and I have assumed that 83 percent of the work done by bullocks was carried out in rural areas (*14*). Thus, if the average bullock worked 1200 hours per year, the total energy expenditure in bullock work in 1971 was 1.61×10^{14} kcal, or 179 billion kwh.

Part of the bullock work in rural areas was used in plowing, cultivating, and harvesting farm fields, part in lifting water for irrigation, and the remainder for transportation. In Bangladesh the observed number of bullock days per hectare ranged from 30 for wheat to 49 for transplanted aman rice and 74 for boro rice (*9*). Taking an average of 40 days per hectare and 8 hours per day, the bullock working time on India's 163 million gross cultivated hectares is 52 billion hours, or 75 percent of the total work time in rural areas. Bullock power was also used to lift 4 to 6 million hectare meters of irrigation water in approximately 4 million "Persian wheels" and other unmotorized wells (*10*). A pair of bullocks is able to lift 1 hectare meter in 600 hours (*15*). The bullock time in lifting water was between 4.8 and 7.2 billion hours, 7 to 10 percent of the total working time in rural areas, and the proportion of the work of rural bullocks used directly in agriculture was 82 to 85 percent, corresponding to about 1.35×10^{14} kcal per year (*16,17*).

Locally Produced Fuels

India is one of the few countries where a systematic attempt has been made to determine the extent of use of "noncommercial" fuels. Sample surveys in villages and towns were conducted by the Energy Survey of India Committee in the early 1960's. The committee reported that about 120 million metric tons of wood, 50 million tons of dried dung, and 30 million tons of "vegetable waste" were burned each year, largely in the villages but also in urban areas (*18*). Later authors have given somewhat higher estimates.

For example, Henderson (*14*) estimates that 126 million tons of firewood was consumed in 1970–1971, of which 83 percent (0.24 ton per person) was burned in rural areas, and Datta (*19*) gives a total of 142 million tons for both rural and urban areas. With an energy content for firewood of 4.4×10^6 kcal per metric ton (*20*), Henderson's estimate corresponds to a total of 4.60×10^{14} kcal (515 billion kwh) of energy supplied annually by burning firewood in rural areas. This is the energy contained in 61.3 million U.N. equivalent tons of coal (139 kg per capita).

In northern India and Nepal, where the winters are cold, per capita consumption of firewood may be much higher than these figures indicate. Makhijani and Poole (*5*) estimate that 1 to 1.5 tons of firewood per person per year is used even in such warm regions as Nigeria and Tanzania.

Many workers have attempted to estimate the quantity of dung produced by livestock in India and the proportion used as fuel. Briscoe (*21*) and Odend'hal (*11*) summarize recent estimates, which range from 1.4 to 3.5 kg of dry dung per head per day, of which 22 to 75 percent is estimated by different authors to be used as fuel. The combined estimates correspond to a range of 120 to 310 million tons per year of dry dung produced by the Indian cattle population of 247 million in 1970–1971 (*13*), and 48 to 97 million tons for the quantity used as fuel. I shall accept Henderson's estimate (*14*) of 68 million tons used as fuel, of which 83 percent was burned in rural areas. Taking the energy content of dried cow dung as 3.3×10^6 kcal per ton (*22*) gives a total of 1.86×10^{14} kcal (207 billion kwh) for 56 million tons of dried dung burned in rural areas, corresponding to 24.8 million U.N. equivalent tons of coal, or 56 kg per capita.

Briscoe (*21*) concludes from data given by several other workers that crop residues from wheat and rice in the Indian subcontinent amount to about 1570 kg per hectare annually. Makhijani and Poole (*5*) give the ratios of straw and chaff to grain from indigenous rice varieties, wheat, and sorghum (called bajra in India) as 2.9, 1.75, and 0.85, respectively. The total Indian food grain production in 1971–1972 was about 105 million tons (*23*), of which approximately 42 percent was rice, 23 percent wheat, and 35 percent other cereals and pulses. Using Makhijani and Poole's ratios, we conclude that the total quantity of straw and chaff residues from food grain production was around 200 million tons, grown on 130 million gross sown hectares, or 1540 kg per hectare, close to Briscoe's figures. Most of these residues were eaten by livestock (providing somewhat less than half of their food energy) but probably about a fifth (39 million tons) was used as fuel (*14*), of which 83 percent was consumed in rural areas. Datta (*19*) gives a smaller estimate of 34.2 million tons for 1968–1969 and the National Sample Survey in 1963–1964 (*24*) indicated a still lower household use. Accepting the figure of 39 million tons and assuming that the energy content of straw and other crop residues is the same as that of dried cow dung (3.3×10^6 kcal per ton), the total energy obtained in rural areas is 1.07×10^{14} kcal (120 billion kwh), corresponding to 14.3 million U.N. equivalent tons of coal, or 32 kg per capita.

In terms of U.N. coal equivalents, the energy derived from burning wood, cow dung, and crop residues adds up to 227 kg per capita per year, or a total for rural India of 100 million tons, with an energy content of 7.53×10^{14} kcal. In Table 4, I have allocated 90 percent of this energy to cooking and space heating and 10 percent to other uses, including pottery and brickmaking, metalworking and blacksmithing, and sugar making.

"Commercial" Energy Sources

In recent years Indian farmers have used around 2 million tons of nitrogen in chemical fertilizers annually (*23*). About 1.55 tons of naphtha and other light petroleum fractions is used as a feedstock and as a source of energy in manufacturing a ton of nitrogen in fertilizer in India (about the same weight of natural gas is used in most imported fertilizers), with an energy content of 11.4×10^6 kcal per ton (*17*). Hence the weight of fossil fuels used in manufacturing 2 million tons of nitrogen in fertilizer is 3.1 million tons, with an energy content of 0.35×10^{14} kcal, corresponding to 4.7 million U.N. equivalent tons of coal or 11 kg per capita per year.

About 16.1 million tons of petroleum

Table 2. Energy expended in human labor in rural India. The energy per hour expended in work (columns 6 and 7) is estimated from data given for various tasks by Passmore and Durnin (*6*), multiplied by 0.7 to account for the fact that humans in India have smaller body sizes than the workers described by Passmore and Durnin and for observed differences between energy expended per hour while working and energy required for specific work tasks.

Occupation	Number of workers (10^6)		Estimated hours worked per year		Energy per hour (kcal)		Total energy expended in work (10^{12} kcal/year)		
	Male	Female	Male	Female	Male	Female	Male	Female	Total
Cultivators*	74.9	4.0	1800†	1000†	250	200	33.7	0.8	34.5
Agricultural laborers*	26.4	21.0	1000‡	1000‡	250	200	6.6	4.2	10.8
Unpaid family workers in cultivation§	40.9	5.0	1550‖	1000‖	200	200	12.7	1.0	13.7
Total directly in agriculture	142.2	30.0					53.0	6.0	59.0
Domestic activities¶		109.4		1800#		200		39.4	39.4
All other occupations**									
Livestock and poultry	1.5		2000		250		0.8		0.8
Fishing	0.5		1500		300		0.2		0.2
Forest products	0.3		2000		300		0.2		0.2
Mining and quarrying	0.4		2000		300		0.2		0.2
Transport and storage	1.3		1500		200		0.4		0.4
Construction	1.5	1.0	1000	1000	250	250	0.4	0.3	0.7
Trade and commerce	3.0		2000		150		0.9		0.9
Other services	7.2	3.0	1500	1000	150	200	1.6	0.6	2.2
Carpentry, wood and straw manufacture	1.8		2000		200		0.7		0.7
Leather industry	0.9		2000		200		0.4		0.4
Metalwork and blacksmithing	1.0		2000		250		0.5		0.5
Pottery and brickmaking	0.7		2000		250		0.4		0.4
Food preparation and milling	0.7	0.8	1500	1500	200	200	0.2	0.2	0.4
Textiles	1.6	1.0	2000	2000	200	150	0.6	0.3	0.9
Miscellaneous	0.5	0.2	2000	2000	200	150	0.2	0.1	0.3
Total, all other occupations	22.9	6.0					7.7	1.5	9.2
Grand total	165.1	145.4					60.7	46.9	107.6

*According to the 1971 census of India (*36*) the total rural population was 439 million (228 million males and 211 million females), of whom 151 million were in the (employed or self-employed) labor force—120 million males and 31 million females. Within this labor force there were 76.8 million cultivators (farmers owning or renting farmland), 45.3 million landless agricultural laborers, and 28.9 million workers in other occupations. In addition, 2.1 million cultivators and an equal number of agricultural laborers lived in urban areas. About 95 percent of the cultivator households were headed by males and 5 percent by females. Most adult females in the families of agricultural laborers work whenever they can find employment, and hence I have assumed that the number of female agricultural laborers was about 80 percent of the number of males. †It is assumed that male and female cultivators work 180 10-hour days and 125 8-hour days, respectively, per year. ‡Landless agricultural laborers suffer from severe underemployment. They are employed mainly during peak periods of labor demand in crop production, such as seedbed preparation, rice transplantation, and harvesting. I have assumed that both males and females are able to find about 100 days of employment per year. §According to the 1961 census of India (*37*) the average household engaged in cultivation, with or without other occupations, had 2.36 family workers, including the head of the household. I have assumed that a large proportion of these were unpaid family agricultural workers, including all males 10 to 14 years of age and 15 million males 15 years or older in cultivator households. Males 10 to 14 years of age in other households are also counted as unpaid family agricultural workers, together with 5 million females. ‖Nearly a third of unpaid male family workers are assumed to be 10- to 14-year-old children of landless laborers helping their parents; hence the number of hours worked by the average unpaid family worker is less than that for cultivators. ¶All females 10 years of age or older not in the labor force or in the category of unpaid family workers are assumed to be engaged in domestic activities. #Domestic activities must take place every day in the year and may require about 5 hours a day per domestic worker. For example, East African women take 46 minutes each day in fetching water and expend on the average 240 kcal (*7*), and these numbers probably apply in India. Collecting wood, straw, and dung for fuel may take several times as much time and energy, perhaps 2 hours a day and 600 kcal. I estimate that procuring and preparing food, cooking, washing, carrying cooked food to farm workers, and other household tasks take at least an additional 2 hours a day per worker. **The proportions of workers in occupations other than farming are estimated from the proportions in major occupational categories in the state of Haryana in 1971 and in industry in all of rural India in 1961 (*36, 37*).

Table 3. Food energy intake and estimated expenditure in work for males and females of different age groups living in rural India, 1971. The values in column 4 are from Table 2.

Age group (years)	Number of people (10^6) (*36*)	Energy per capita (10^6 kcal/year)		Energy intake expended in work (%)
		Food intake (*8*)	Expended in work	
0 to 9	133.3	0.55		
10 to 14				
Males	25.9	0.91	0.32	35
Females	23.3	0.85	0.36	42
15 and older				
Males	135.0	1.03	0.39	38
Females	122.1	0.73	0.32	44
Total	439.6			
Averages		0.78	0.24	31

products were used as fuel in India in 1970–1971 (*14*). Farm usage, mainly as diesel fuel to pump water for irrigation and to a small extent for tractors, was 4.6 percent of this amount or 0.74 million tons, and household usage, mainly kerosene for lighting, was 28.3 percent or 4.56 million tons. Assuming that per capita household usage was the same in the country as in the city, rural households used 80 percent of 4.56 million tons, or 3.65 million tons, and total rural use on farms and in households was 4.39 million tons of petroleum products, with an energy content of 0.50×10^{14} kcal (56 billion kwh), corresponding to 15 U.N. equivalent kilograms of coal per capita. In addition, a considerable quantity of petroleum products was used as fuel for trucks and other vehicles, in part for transportation of farm products and fertilizers and other agricultural inputs between rural and urban areas, but I have not tried to account for this.

Henderson (*14*) estimates that 4.1 tons of soft coke made from coal was used in households in 1970–1971. Consumption per capita was probably at least twice as high in cities as in rural areas. Average per capita coke consumption in rural areas was then 6.2 kg per year. If the energy content of this coke was the same as that of Indian coal (5.2×10^6 kcal per ton) the total energy in coke used in rural areas was 0.14×10^{14} kcal, or a U.N. coal equivalent per capita of 4 kg per year.

In 1970–1971, 9.2 percent of 48.6 billion kwh of electricity consumed in India was used in agriculture, mainly for irrigation, or 4.5 billion kwh (0.04×10^{14} kcal). In addition, 3.8 billion kwh was used in households. Villages containing 36 percent of the rural population (160 million people) were electrified. Except for irrigation, per capita consumption of electricity is lower in rural than in urban areas, but since the urban population was only 110 million people we may assume that half of the household use occurred in rural villages, or 1.9 billion kwh (0.02×10^{14} kcal). With this assumption, the average per capita consumption of electricity for all purposes in rural areas was 0.04 kwh per day (*14*).

Hydroelectric power accounted for 45 percent of electricity generated in India in 1970–1971 and thermal power (including nuclear) accounted for 55 percent (*14*). Applying this ratio to electricity consumption in rural areas, we obtain 2.9 and 3.5 billion kwh for the total hydroelectric and thermal energy consumed. Indian thermal generating plants have an average efficiency of 22 percent for conversion of heat energy to electricity (*14*). Subtracting transmission losses and electricity used in power generation, the net electricity consumption is 83 percent of electricity generated. Hence 1 ton of Indian coal with an energy content of 5.2×10^6 kcal is burned to generate 1000 kwh of electricity consumed (*22*). If coal were used exclusively, the coal required for 3.5 billion kwh electrical would be 3.5 million tons (actually a considerable fraction of total electricity is generated from heavy fuel oil). The U.N. coal equivalent at 18 percent consumptive efficiency is 1500 kwh per ton of coal. Hence the U.N. coal equivalent per capita of thermal electricity consumed in rural areas was 5 kg. Taking the consumptive efficiency of hydroelectric power as 70 percent, the U.N. coal equivalent for hydroelectric energy is 2 kg per capita.

In terms of U.N. coal equivalents, the commercial energy use per capita in rural India in 1971 was 37 kg, and the total for the rural population was 16.3 million tons, with an energy content of 1.20×10^{14} kcal. In Table 4, I estimate that 12 percent of this commercial energy was used for cooking and space heating (soft coke), 40 percent for lighting (mainly kerosene and a small quantity of electricity), and 48 percent for agriculture (petroleum products used in manufacturing nitrogen fertilizer, and electricity and diesel fuel).

Fuel Efficiency in Cooking

The total energy from local and commercial fuels used in cooking and space heating was 6.9×10^{14} kcal, or 1.57×10^6 kcal per capita per year, approximately twice the energy in food eaten. If space heating can be neglected, the energy use in cooking per calorie of food energy consumed was higher than the estimated U.S. energy use per food calorie for cooking and home refrigeration combined (*25*).

Two experiments with rice cooking showed that the energy required to bring the cooking water to boiling and to boil away the requisite quantity of water is about 600 kcal/kg, or 17.5 percent of the food energy content of rice. Assuming that other food grains behave in a similar fashion, and that 75 percent of the energy from fuels used in cooking and space heating went into cooking food grains, the efficiency of fuel use was less than 9 percent. This may be compared with an energy efficiency of 30 to 60 percent in cooking on a modern gas stove (without pilot lights) in the United States (*5*).

The large-scale burning of firewood as a source of energy for cooking and space heating has serious implications. Until recent years, forests had completely disappeared from most of China, because the trees had been cut down for fuel. It is likely that a similar process is now occurring in much of India. The total forested area is about 75 million hectares, of which 80 percent is actually or potentially usable. According to Prasad *et al.* (*26*), forest areas contain 50 tons of wood per hectare. Thus the present reserves, if all were used for firewood, are $7.5 \times 10^7 \times 0.8 \times 50 = 3 \times 10^9$ tons, or enough to last for 24 years at present annual rates of consumption, without taking into account new growth. Two other serious problems are the very uneven distribution of the forests, with 50 percent of the forested area in four states (Madhya Pradesh, Orissa, Andhra Pradesh, and Maharashtra) that have less than 20 percent of the population, and deforestation of mountainous regions. These are the watersheds for the great rivers that flow through the plains. With the growth of human populations, the forests are being cut down faster than they can grow, partly to make room for new farmlands, and partly for use as fuel. As a consequence, the upland areas are subjected to destructive erosion, while the resulting sediments cause rapid filling of reservoirs and destructive floods in the downstream areas (*10*). Small, run-of-the-river hydroelectric generators (*27*) might provide a substitute source of energy for the mountain and hill peoples and thereby help to conserve the forests.

Intensive reforestation programs will be necessary if India's forests are not to disappear. Actually, reforestation could considerably increase present energy supplies. Parikh (*22*) estimates potential annual production in forest plantations at 12.5 metric tons per hectare. Thus, the potential annual production under intensive reforestation could be 7.2×10^8 tons, about six times the present annual consumption of firewood.

In the short term, improved stoves and other means for increasing the efficiency of fuels used for cooking and for heating water would appear to be the most promising energy conservation measures.

Comparison of the United States and Rural India

In Table 4, the quantities and uses of energy from different sources are summarized. Energy utilized per person in 1971 was 7.1×10^3 kcal per day, 3.3 times the energy in food consumed [estimated as 2.15×10^3 kcal per day (*8*)]. In terms of U.N. coal equivalents, the annual energy expenditure corresponds to 0.346 ton per capita, compared with 11.15 tons per capita in the United States in 1970 (*1*). More than 89 percent of this energy was provided by the villagers themselves and less than 11 percent was from commercial sources, whereas nearly all the energy accounted for in the United States is from fossil fuels and hydroelectric power.

The total quantity of energy utilized in rural India in 1971 was 11.4×10^{14} kcal per year, probably somewhat more than the total used on farms and in farming households in the United States [estimated as roughly 10.65×10^{14} kcal (*28*)]. But the per capita use by the U.S. farm population of 9.5 million was 50 times greater than that of India's 440 million rural people.

Steinhart and Steinhart (*25*) estimate that the energy used in all components of the U.S. "food system," including 5.26×10^{14} kcal on farms, 11.66×10^{14} kcal in the food processing and marketing industries, and 4.8×10^{14} kcal in home refrigeration and cooking, is about nine times the energy in food eaten. Assuming that 80 percent of the food produced and energy consumed in Indian agriculture is chargeable to rural areas, the corresponding figure for agriculture and cooking in rural India is slightly less than 2.7 kcal per 1 kcal of food eaten, depending on the (probably small) amount of fuel used for space heating. But the energy utilized in the U.S. food system is less than 13 percent of total U.S. energy use (*25*), whereas 82 percent of total energy use in rural India is directly related to food.

Dividing Steinhart and Steinhart's estimate of 5.26×10^{14} kcal used on farms in the United States by the 1971 cropped area of 122 million hectares, we obtain an energy use per hectare of 4.31×10^6 kcal, nearly three times our computed value from Table 4 of 1.55×10^6 kcal per hectare on India's gross cropped area of 163 million hectares. Estimates by Pimentel *et al.* (*29*) of energy expenditure in production of food grains (cereals and soybeans) and animal products (meat, eggs, poultry, and milk products) in the United States give a total of 9.2×10^{14} kcal for the 108 million cropped hectares used for these purposes, or 8.52×10^6 kcal per hectare, about twice the value derived from the data of Steinhart and Steinhart. Approximately 55 percent of this energy (5.06×10^{14} kcal) was used on cultivated fields and 45 percent (4.14×10^{14} kcal) in the care and management of animals.

It is difficult to compare the energy expenditures per unit of human food in India and the United States because of the very different diets of the two peoples. Comparison is easier if we consider only food grains, which make up 81 percent of the Indian diet but only 21 percent of the U.S. diet (*30*). The data given by Pimentel *et al.* (*29*) indicate that 4.3×10^{14} kcal is used in U.S. agriculture to produce 271 million tons of corn, wheat, sorghum, other cereals, and soybeans, or 1.59×10^6 kcal per ton. This is 45 percent of the food energy in the crops. Assuming that 80 percent of energy expenditure in Indian agriculture goes to food grain production, which totaled 105 million tons in 1971–1972 (*23*), the energy expenditure per ton was 1.92×10^6 kcal, 55 percent of the food energy. Most of this was in the form of human and animal work. Insofar as energy costs are reflected in food grain prices, such work is apparently more costly than mechanical work based on fossil fuels, even under Indian conditions.

Throughout the decade 1960–1970,

Table 4. Energy uses in rural India. Except for human labor, quantities and uses of energy from different sources are given in the text.

Source of energy	Energy used (kcal)					
	Agriculture	Domestic activities	Lighting	Pottery, brickmaking, metalwork	Transportation and other uses	Total
Human labor*	0.59×10^{14}	0.39×10^{14}		0.01×10^{14}	0.09×10^{14}	1.08×10^{14}
Bullock work	1.35×10^{14}				0.26×10^{14}	1.61×10^{14}
Firewood and charcoal						4.60×10^{14}
Cattle dung		6.78×10^{14}		0.75×10^{14}		1.86×10^{14}
Crop residues						1.07×10^{14}
Total from local sources	1.94×10^{14}	7.17×10^{14}		0.76×10^{14}	0.35×10^{14}	10.22×10^{14}
Petroleum and natural gas						
Fertilizer	0.35×10^{14}					0.35×10^{14}
Fuel	0.08×10^{14}		0.42×10^{14}			0.50×10^{14}
Soft coke		0.14×10^{14}				0.14×10^{14}
Electricity						
Hydro†	0.03×10^{14}		0.01×10^{14}			0.04×10^{14}
Thermal‡	0.12×10^{14}		0.05×10^{14}			0.17×10^{14}
Total from commercial sources	0.58×10^{14}	0.14×10^{14}	0.48×10^{14}			1.20×10^{14}
Total, local and commercial	2.52×10^{14}	7.31×10^{14}	0.48×10^{14}	0.76×10^{14}	0.35×10^{14}	11.42×10^{14}
Daily per capita	1.57×10^3	4.55×10^3	0.30×10^3	0.47×10^3	0.22×10^3	7.11×10^3

*See Table 2. †Potential energy in water used to generate hydroelectric power. ‡Energy in coal used to generate thermoelectric power.

when grain prices were relatively stable, wholesale prices of wheat, sorghum, and corn in the United States averaged \$54, \$45, and \$45 per ton, respectively (*31*), while during the same period in India average wholesale wheat and sorghum prices were \$107 and \$73 per ton (*32*). World prices of these cereals were about the same as U.S. prices. Only rice, which made up about 1 percent of U.S. food grain production but more than 40 percent of Indian production, was somewhat higher-priced in the United States, averaging \$162 per ton compared to \$142 per ton in India. The average wholesale price of a ton of soybeans in the United States was \$92. Pulses in India averaged \$128 per ton at wholesale.

The average Indian spent the equivalent of \$48.60 each year on food and beverages, of which about \$40 went for a total of 2060 kcal per day in food grains, sugar, fruit, vegetables, and vegetable oil (*33*). The farmers' share was 80 to 90 percent of these expenditures, or about \$17 per thousand kilocalories per day (*32*). In 1970, the American farmers' share of per capita food expenditures in the United States was about \$200 (*4*). The equivalent of humanly edible plant energy in the American diet is 10,900 kcal per day—2000 kcal in plant food eaten directly and 8900 kcal in food grains fed to animals (*29, 30*). Thus American farmers received a little more than \$18 per thousand plant calories per day for the average American's diet, very close to the Indian figure. This is in spite of the fact that a large part of American costs were chargeable to the care and management of livestock and poultry.

More Energy Is Needed in India

In order to reduce the costs and energy expenditures per ton of food produced, let alone provide enough food for the population of 1000 million expected by the year 2000, a considerable increase in energy use will be essential, primarily for three purposes: irrigation, chemical fertilizers, and additional draft power for cultivating the fields. The climate and water supply permit growing two crops per year on most of India's arable land, but this will be possible only if facilities for surface and groundwater irrigation are greatly expanded and if abundant nitrogen fertilizers can be made available, so that the fields do not have to be left fallow to accumulate nitrogen. Estimates by the Indian Irrigation Commission indicate that with full irrigation development, about 46 million net hectare meters should be pumped annually from wells (*10*), requiring at least 1×10^{14} kcal of fuel energy, four times the bullock, diesel, and electric energy now used. Applications of nitrogen fertilizer should be raised to around 100 kg per hectare per crop, or 20 million tons for 100 million double-cropped hectares, with an energy requirement of 3.5×10^{14} kcal (*17*).

More draft power is needed than can be obtained from bullocks, because rapid seedbed preparation is necessary to grow two crops per year. Makhijani and Poole (*5*) estimate that an additional 5×10^5 kcal per hectare per crop is required for construction and operation of small tractors, or 1×10^{14} kcal, supposing that 100 million acres are double-cropped. Cultivation of two crops per year would greatly increase farm employment, probably by at least 50 percent, corresponding to an added human energy input of 0.3×10^{14} kcal per year (*34*). The total additional energy requirement is 5.2×10^{14} kcal, more than twice the energy now used in Indian agriculture. With these added energy inputs it would be possible, in principle, to approximate the average U.S. yield of 3.28 tons per hectare per crop for food grains (*1*), instead of the present 0.8 ton.

Assuming a yield of 2 tons per hectare per crop and double-cropping on 100 million hectares, food grain production could be raised to between 300 and 400 million tons, depending on the farmland devoted to other crops. This is between three and four times present production and would have a value at 1976 world prices of \$35 billion or more. The input of energy from all sources per ton of food grains would be on the order of 1.8×10^6 kcal, significantly less than at present. If the average yields per hectare attained in U.S. food grain production were achieved, the energy input would be about 1.1×10^6 kcal per ton of food grains.

Where Would the Energy Come From?

With present technology the additional energy required for draft power, pumping water, and manufacturing chemical fertilizers would have to be provided largely by fossil fuels and hydroelectric power. If the requirement were met by using petroleum products, 43 million tons would be needed, more than twice the quantity used at present in all of India, costing at today's world prices \$3.2 billion. Alternatively, 95 million tons of Indian coal could be used. These figures might be significantly reduced by development of the Indian and Nepalese hydroelectric power potential, which is probably from 50,000 to 100,000 megawatts (*35*).

Even if all the additional energy came from petroleum products, and all this petroleum were imported, the cost could be met by exporting about a tenth of the increased food grain production. But the crop residues remaining from 300 million tons of food grains would be at least 400 million tons, with an energy content of 13×10^{14} kcal, about 2⅔ times the required additional energy. If this energy provided by photosynthesis could be harnessed, for example in nitrogen-conserving fermentation plants of the type suggested by Makhijani and Poole (*5*), the Indian rural ecosystem could continue to be fairly self-sufficient. A major long-range research and development effort along these lines would be of inestimable value.

Summary

An old saying has it, "slavery will persist until the loom weaves itself." 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. The men and women of rural India are tied to poverty and misery because they use too little energy and use it inefficiently, and nearly all they use is secured by their own physical efforts. A transformation of rural Indian society could be brought about by increasing the quantity and improving the technology of energy use.

References and Notes

1. U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States* (Washington, D.C., ed. 93, 1972).
2. J. L. Fisher and N. Potter, in *Rapid Population Growth: Consequences and Policy Implications* (National Academy of Sciences, Johns Hopkins Press, Baltimore, 1971), pp. 222–244.
3. In U.N. statistical publications 1 equivalent ton of coal corresponds to 7.5×10^6 kcal of usable energy. In India 103 million U.N. equivalent tons of coal from commercial sources was used in 1970 (*1*). I estimate that 16 million tons was used in rural areas, leaving 87 million tons for urban use. Noncommercial energy use in rural and urban areas corresponds respectively to 136 and 28 million U.N. equivalent tons of coal, and total energy use is 267 million tons for a population of 550 million people, or 486 kg per capita.
4. D. Pimentel, L. E. Hurd, A. C. Bellotti, M. J. Forster, I. N. Oka, O. D. Sholes, R. J. Whitman, in *Energy: Use Conservation and Supply*, P. H. Abelson, Ed. (AAAS, Washington, D.C., 1974), pp. 41–47.
5. A. Makhijani and A. Poole, *Energy and Agriculture in the Third World* (Ballinger, Cambridge, Mass., 1975), pp. xv and 168.
6. R. Passmore and J. V. G. A. Durnin, *Physiol. Rev.* **35**, 801 (1955).
7. G. F. White, D. J. Bradley, A. U. White, *Drawers of Water* (Univ. of Chicago Press, Chicago, 1972), pp. 93–107.

8. President's Science Advisory Committee, Panel on World Food Supply, *The World Food Problem* (The White House, Washington, D.C., 1967), vol. 2, chap. 1.
9. International Bank for Reconstruction and Development, *Bangladesh Land and Water Resources Sector Study* (Washington, D.C., 1972).
10. Ministry of Irrigation and Power, Government of India, *Report of the Irrigation Commission, 1972* (New Delhi, 1972), vol. 1, pp. 41–56 and 201–246.
11. S. Odend'hal, *Hum. Ecol.* **1**, 3 (1972).
12. M. Harris, *Curr. Anthropol.* **7**, 51 (1966).
13. R. K. Bhatia and M. Mehta, *Tubewell Irrigation in India: An Economic Analysis of Some Technical Alternatives* (working paper, Harvard Center for Population Studies, Cambridge, Mass., 1975).
14. P. D. Henderson, *India: The Energy Sector* (International Bank for Reconstruction and Development, Washington, D.C., 1975).
15. Meta Systems, Inc., *Working Draft Report: Analysis of "Revelle" Polders Development Scheme and Design for a Long Range Lake Chad Basin Study* (Cambridge, Mass., 1974), pp. 52–110.
16. The Ministry of Food, Agriculture, Community Development, and Cooperation, Government of India [*Farm Management in India* (New Delhi, 1966)], quoted in (*17*), estimates 642 bullock-hours and 615 man-hours per hectare for wheat production in Uttar Pradesh. Using my estimates of energy input per hour, the total expenditure of bullock and human energy per hectare was 1.63×10^6 kcal, or 57 percent of the food energy in the wheat crop. Pimentel (*17*), using his method of computing human and bullock energy expenditures, gives 2.85×10^6 kcal per hectare, about equal to the energy in the wheat. Table 4 indicates that for a gross cropped area of 163 million hectares, average human and bullock energy expenditure in Indian agriculture is 1.18×10^6 kcal per hectare, 28 percent smaller than the Ministry's figure.
17. D. Pimentel, *Energy Use in World Food Production* (Report 74-1, Department of Entomology and Section of Ecology and Systematics, Cornell University, Ithaca, N.Y., 1974), tables 6 and 15.
18. Government of India, *Report of the Energy Survey of India Committee* (New Delhi, 1965).
19. R. L. Datta, in *Solar Energy in Developing Countries: Perspectives and Prospects* (National Academy of Sciences, Washington, D.C., 1972), pp. 40–46.
20. T. B. Reed and R. M. Lerner, in *Energy: Use Conservation and Supply*, P. H. Abelson, Ed. (AAAS, Washington, D.C., 1974), pp. 131–136.
21. J. Briscoe, thesis, Harvard University (1976).
22. K. S. Parikh, *India in 2001—Fuels or Second India and Energy* (Discussion Paper No. 105, Indian Statistical Institute, New Delhi, 1974).
23. J. D. Gavan and J. A. Dixon, *Science* **188**, 541 (1975).
24. Indian Statistical Institute, Government of India, *National Sample Survey, 18th Round, February 1963–January 1964* (New Delhi, 1964).
25. J. S. Steinhart and C. E. Steinhart, *Science* **184**, 307 (1974).
26. C. R. Prasad, K. K. Prasad, A. K. N. Reddy, *Econ. Polit. Wkly.* **9**, 1347 (1974).
27. P. Steadman, *Energy Environment and Building* (Cambridge Univ. Press, Cambridge, 1975).
28. Since the average income of farm families from all sources is 71 percent of the median income of all families in the United States (*1*), we assume that the farm energy use per capita outside farming operations is 71 percent of the U.S. average of 80.8×10^6 kcal per capita, or a total of 5.40×10^{14} kcal for 9.5 million persons living on farms. Adding the estimate by Steinhart and Steinhart (*25*) of 5.26×10^{14} kcal for farming operations gives a total of 10.66×10^{14} kcal used annually on U.S. farms.
29. D. Pimentel, W. Dritschilo, J. Krummel, J. Kutzman, *Science* **190**, 754 (1975).
30. R. Revelle, in *The Human Population* (Freeman, San Francisco, 1975), pp. 163–170.
31. U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States* (Washington, D.C., eds. 81 to 92, 1960 to 1971).
32. J. R. Moore, S. S. Johl, A. M. Khusro, *Indian Food Grain Marketing* (Prentice-Hall of India, New Delhi, 1973), pp. 41–76. I have converted prices given in rupees into dollars using an exchange rate of $1 = 4.76 rupees up to 1966 and $1 = 7.50 rupees in 1966 and thereafter.
33. V. M. Rao, *Second India Studies, Food* (Macmillan, New Delhi, 1975), pp. 12–14.
34. R. Krishna, *Indian J. Agric. Econ.* **28**, 20 (1973).
35. International Bank for Reconstruction and Development, *Nepal, Irrigation and Water Resources Development* (Washington, D.C., 1974), pp. 7–11.
36. Office of the Registrar General, Government of India, *Census of India, 1971* (New Delhi, 1972–1975), in various parts.
37. Office of the Registrar General, Government of India, *Census of India, 1961* (New Delhi, 1962–1965), in various parts.

38. I thank my colleagues in the resources development group of the Harvard Center for Population Studies for many helpful discussions, in particular R. Bhatia, J. Briscoe, J. Gavan, P. Rogers, and R. D. Tabors. This article is based in part on a paper presented at a conference sponsored by the U.S. Agency for International Development at the Georgia Institute of Technology in 1974.

NEWS AND COMMENT

Nuclear Initiative: Impending Vote Stimulates Legislative Action

San Francisco. The "nuclear power plant initiative," which comes to a popular vote on 8 June after a long, hotly contested campaign, is challenging the powerful establishment that has been promoting the rapid development of nuclear energy in California. If adopted by the voters, the initiative would give a boost to similar initiative efforts now under way in more than a dozen other states. But the one sure effect of this forthcoming plebiscite is its strong encouragement of a serious effort by the California legislature to demand that utilities and federal regulators solve the problems currently besetting the nuclear enterprise and provide convincing assurances about nuclear safety.

The initiative, or proposition 15 as it is called, is characterized by its proponents as a measure to bring about nuclear "safeguards" and by its opponents as one cleverly and deceptively designed to achieve a nuclear "shutdown." In fact, the motivations behind the initiative seem quite mixed. Some of its backers are clearly "antinuclear" while many others simply believe that nuclear power can and should be made safer than it now is. Yet there is little doubt but what approval of the initiative would bring about at least a temporary slowdown or cessation of nuclear power generation and development over the next 5 years by imposing, in the case of all new and existing reactors, stringent demands as to insurance liability, safety, and radioactive waste disposal.

Californians have been bombarded with propaganda for and against proposition 15 ever since late 1974, when its sponsors began circulating petitions to get it on the ballot. Not surprisingly, after more than a year and a half of this loud and confusing debate, most citizens apparently are still trying to make up their minds how they will vote.

Leading the initiative campaign is the Committee for Nuclear Safeguards, headed by David Pesonen, a San Francisco attorney and former forester and Sierra Club representative. In collecting the half million signatures necessary to qualify the proposition for the ballot, Pesonen was aided by the People's Lobby, a southern California group which has made a specialty of pushing initiative campaigns, and by Project Survival, a new activist group based in Palo Alto. Known for its dedication and effectiveness, this latter group—a political spin-off from a philosophical and semireligious organization known as Creative Initiative—probably kept the signature drive from foundering.

Proposition 15 also has the support of most California environmentalists, and groups such as the Sierra Club and Friends of the Earth are deeply committed to it. On California's college and university campuses, there is substantial faculty sentiment both for and against the initiative, but the majority of students are believed to support it.

By far the greater part of California's political and business establishment is opposing the proposition. Formally leading the opposition is the California Committee for Environmental and Economic Balance, which represents a coalition of labor unions, utilities, and various other business and development interests. Former Governor Edmund G. Brown, Sr., heads the committee. His son, the present governor of California, has avoided committing himself on the proposition; but several state agencies, including the state energy commission and