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I. THE NATURE OF THE ENERGY CRISIS IN LDC's

The energy problems of the last decades of the 20th century will probably pass into history as the transitory problems of societies which coupled their growth and development to the consumption of irreplaceable fossil fuels.

Table I shows the current levels of energy consumption for some selected countries and world regions.

As can be seen in this Table yearly per capita consumption ranges from 0.18 TCE in the lower-income countries, to 0.6 in India and to 12.8 in the U.S., with a world average of 2.23 TCE. Of the total world energy budget (8.9×10^9 TCE) 69% is consumed in the developed countries, which account for only 25% of the total population. The U.S., with 5.3% of the world's population, consumes over 30% of the world's energy.

Lecture notes of a course given at the International School of Energetics (4th course - Energy Demand and Efficient Use) - Erice - Sicily - July 15-24/1980.

Table 1. Energy Consumption of World Regions and Some Selected Countries

	Population (billions)	Billions of TCE*/year			Energy/capita		Source
		Comm.	Non-Comm.**	Total	TCE/cap.	kcal/day	
World	4.0	7.4	1.5	8.9	2.23	42,500	Ref. 1
Developed Countries	1.05	6.1	---	6.1	5.8	110,000	Ref. 1
Developing Countries	2.95	1.3	1.5	2.8	0.95	18,000	Ref. 1
Middle-Income*** Countries	0.55	0.37	?	0.37	0.67	12,700	Ref. 1
Lower-Income*** Countries	0.89	0.16	?	0.16	0.19	3,400	Ref. 1
Brazil	0.11	0.10	0.03	0.13	1.2	22,800	Ref. 2
India	0.6	0.16	0.2	0.36	0.6	11,000	Ref. 3
China	0.878	0.377	?	0.377	0.384	7,100	Ref. 4
Bangladesh	0.08	0.002	0.007	0.009	0.12	2,300	Ref. 5
U S	0.214	2.7	---	2.7	12.8	243,000	Ref. 1

* 1 kg of coal = 8.6 kwh = $7.4\text{x}10^6$ cal = $3\text{x}10^4$ BTU

** Non-commercial sources are mainly fuel, wood, crop wastes and dung.

*** We used a classification of less developed countries as lower-income LDC's (annual per capita income under US $200) and middle income LDC's (income over US $200 and below US $1,000). See Appendix I.

It is very doubtful that these variations will persist for many decades due to social and political changes around the world. As LDC's develop, their share of the world energy budget tends to grow, which increases the competition for the fossil fuel resources that are not altogether very large. This tendency for an "equalization" of the levels of energy consumption is very strong and unless managed in a satisfactory way will certainly generate conflicts in the rush to gain access to and/or control over fossil fuels.

In addition to that at the current growth rate of 2.1%[1] per year the world's population will reach 10 billion by year 2010; if at that time the "per capita" energy consumption were 12.8 TCE (tons of coal equivalent), the current level of the average U.S. citizen, the total energy consumption per year would be approximately 128×10^9 TCE (3500 Quads).

At this rate of consumption presently known deposits of coal, oil and natural gas would not last more than 60 years, with growing shortages and consequently rising prices occurring much before that. The world's energy problems resides therefore in the fact that the bulk of the energy being consumed comes from fossil fuels which are available in rather limited supplies (Table 2).

In order to understand the differences (and similarities) between developed and LDC's it is useful to review some of the data available for demand of energy in selected countries.

Table 2. World Non-Renewable Energy Resources

	Potential Resource (Billions TCE)
Coal	7,000
Oil	400
Natural gas	400

Source: Ref. 1

Data for developed countries Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Sweden, UK, US are available from a number of studies and we used here as a general reference the information given in the WAES study[6]. In this study the economy is divided in a set of separate sectors (transportation, industrial, residential, etc.) and the energy inputs classified as coal, petroleum, etc. It is important to stress that only commercial sources of energy are used. Figure 1 shows the demand of energy for the developed countries and a few additional LDC's: India,[3] Brazil,[2] Bangladesh[5] and China.[4]

What is striking in this figure is that demand profiles do not differ much for all countries considered.

The situation does change however when one takes into account non-commercial sources of energy in the few cases where they are known (India,[3] Brazil,[2] China,[4] Bangladesh[5]), or have been estimated (East Africa[7] and Central American countries[8]) (Table 3).

Table 3. Commercial and Non Commercial Energy Consumption in LDC's

	Comm.	Non Comm.	Total	Source
India	48%	52%	100%	Ref. 3
Brazil	70%	30%	100%	Ref. 2
China	70%	30%	100%	Ref. 4
East Africa	10%	90%	100%	Ref. 7
Bangladesh	26%	74%	100%	Ref. 5
Costa Rica	69%	31%	100%	Ref. 8
El Salvador	54%	46%	100%	Ref. 8
Guatemala	52%	48%	100%	Ref. 8
Honduras	52%	48%	100%	Ref. 8
Nicaragua	66%	36%	100%	Ref. 8
Panama	81%	19%	100%	Ref. 8

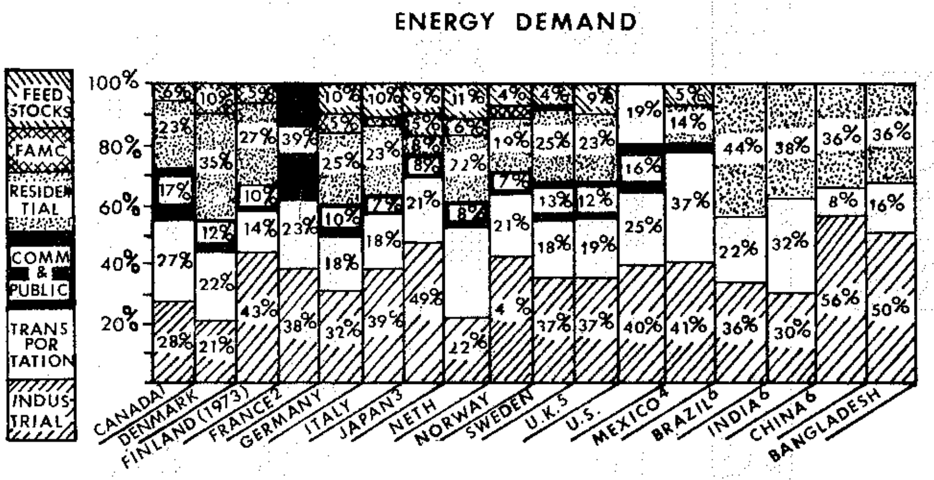

Fig. 1 - Energy demand for developed and LDC's - commercial sources

1-Fishing, agriculture, mining and construction are aggregated into other sectors.
2-Only three sectors are shown: domestic (including residential and commercial), transportation and industry.
3-Transportation includes bunkers.
4-FAMC is 1% - FAMC: fishing, agriculture, mining and construction.
5-Commercial and public also includes fishing and agriculture.
6-Commercial public, residential, fishing, agriculture lumped together as residential.

Figure 2 shows the energy demand by different sectors of the economy including commercial and non-commercial sources. We have introduced here a model developed country obtained by averaging the demand patterns of the developed countries given in Figure 1 (for which non-commercial sources are negligible) and lumped together the residential, commercial, public, fishing and agriculture sectors. Although a weighted average (using as weights the total energy consumed by each country) might be better this would make the US role too dominant. A simple average takes more into account diversities of geography and life-styles within the developed countries.

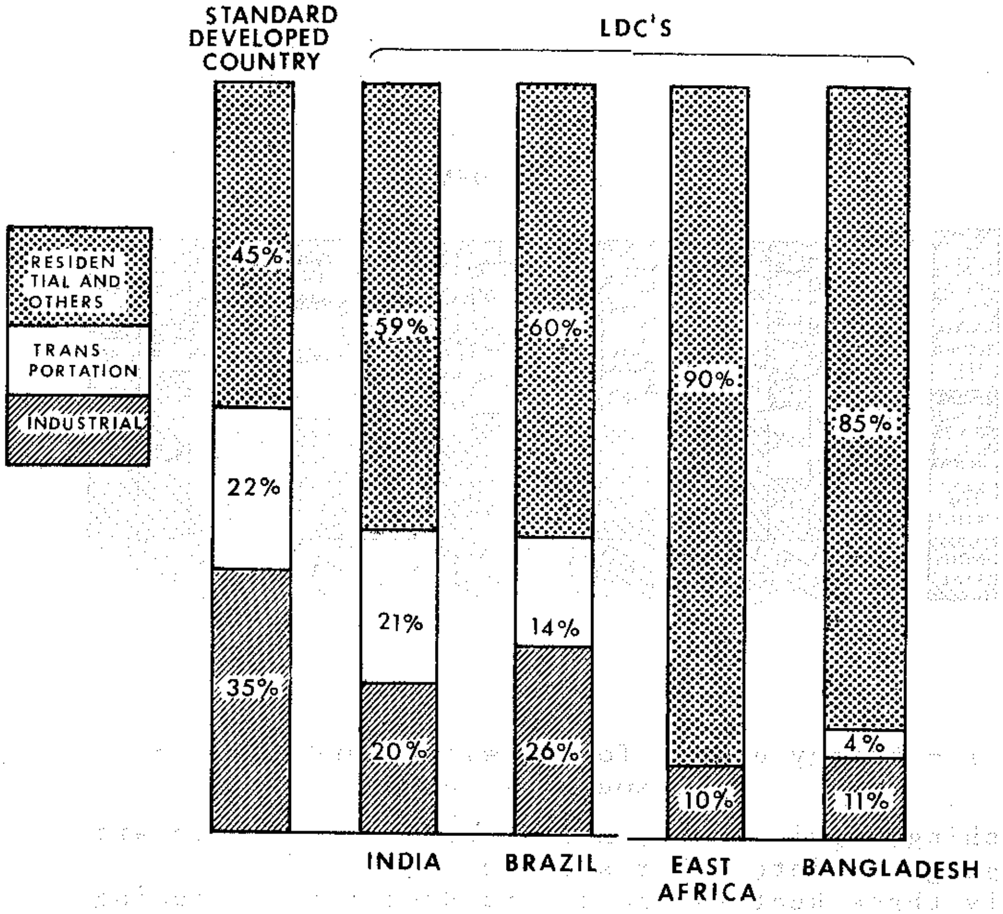

Fig. 2 - Energy demand for developed and LDC's; all sources (commercial and non-commercial)

The major difference between the demand profiles of the developed countries and the LDC's is the much greater importance of the domestic sector in the LDC's, where it accounts for at least 60% of total energy use (90% for East Africa and 85% for Bangladesh), compared to approximately 40% in the developed countries. This reflects the demand profile one intuitively expects for LDC's but which is not apparent in Figure 1, which shows only commercial sources. Even Bangladesh, which is a fairly undeveloped country (with an income per capita of US $110) presents in Figure 1 a consumption profile similar to that of industrialized countries.

The reason for the similarity of the profiles based on commercial energy is the following: most of middle-income (and some of the lower income) LDC's have a social structure that is dual in character: 80-90% of the population live in backward agricultural areas (or in shacks in the urban areas) and do not really participate in the economic life of the country; and 10-20% is quite affluent, living in big cities with cosmopolitan life-styles, and accounts for most commercial energy consumption in the country.

The urban fraction of the population (and its leadership) determine the development policies which consist in general of pushing the leading industrial sectors and waiting for the results to "trickle down" to the people outside of the rapidly expanding economy.

This development model which is widespread in Latin America and Southeast Asia is often described as the "Belgium inside India model" for obvious reasons. There are effectively two countries in one to deal with in most cases and average energy consumption and GNP/per capita have to be analyzed with great caution.

The rural/urban population mix has been changing rapidly in LDC's. In general rural life and social organization in the fields is such that the peasant, owning no land, cannot expect, even working very hard, to improve his living conditions. Consequently many migrate to the large cities whenever possible living in shacks which might appear unbearable to the well established urban dwellers but nevertheless constitutes a progress of sorts for the migrants from rural areas; they can get in cities a few things such as medical aid, school for the children and some amenities such as lighting and TV and radio entertainment they can't have in the fields.

On a worldwide basis the problem of urbanization can be seen clearly in Figure 3; the rural population which was 80% in 1900 has decreased to 65% in 1975 and will probably go down to 45% by the year 2000.[9]

In the developed countries less than 35% of the population lives in rural areas (down from 70% in 1900). The decrease of rural population has been rapid and accelerating for these countries.

In the LDC's approximately 90% of the population was rural in 1900 and this number has decreased slowly to 75% in 1975.

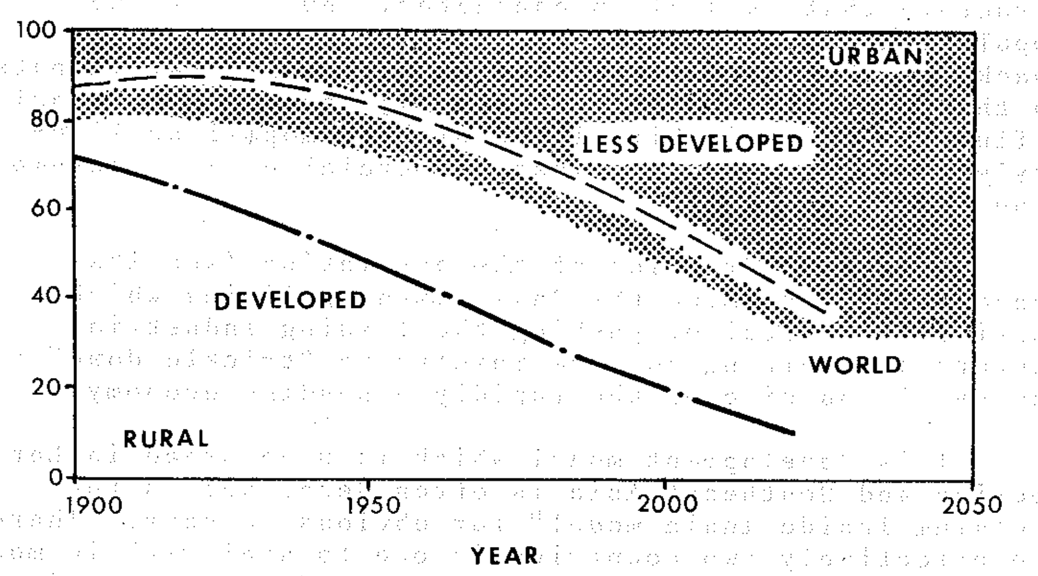

Fig. 3 - Evolution of the world population in rural and urban areas

As pointed out above the main difference between developed and LDC's countries lies in the fact that LDC's depend on non-commercial sources of energy to account for at least 30% (and generally much more than that) of their needs.

Table 4 shows how energy use is distributed by energy consuming sector and by source in the U.S. This distribution is typical of developed countries.

At the other extreme we show in Table 5 the input-output energy matrix for a typical Indian village[10] (population $\leq$ 500).

Data on villages in Bangladesh[11] and in villages in China, Tanzania, Northern Nigeria, Northern Mexico and Bolivia[12] confirm the picture suggested by these data. These patterns are probably characteristic of a total population of over 2 billion people in the LDC's (Table 6).

Table 4. Energy Input-output Matrix for the U.S. (1972)

Energy Source	Energy Consuming Activity (kcal/capita/day)*					
	Agriculture Mining and Others	Commercial	Residential	Transport	Industrial	Total
Oil	5,500	3,300	13,000	59,000	17,000	97,000
Coal	-----	700	------	------	14,000	15,000
Natural Gas	1,000	6,000	20,000	------	26,000	53,000
Electricity	500	5,000	6,000	------	7,000	17,000
Total	7,000	15,000	39,000	59,000	64,000	184,000

*20,000 kcal/capita/day corresponds to an available power of 1 kw.

Source: Reference 6. Not included in this table is the amount of energy lost in the production of electricity from coal, oil and synthetic gas which is approximately 60,000 kcal/capita/day (25% of the total energy consumption).

Table 5. Energy Input-output Matrix for Typical Indian Village

Energy Source	Energy Consuming Activity (kcal/capita/day)					
	Agriculture	Domestic Activities	Lighting	Transport	Manufacturing	Total
Human Labor	370	250	---------	60	10	690
Animal Work	840	---	---------	160	--	1,000
Non-commercial energy (wood, dung, crop residues)	---	4,200	---------	---	460	4,660
Oil	270	-----	260	---	---	530
Coal	---	100	---	---	---	100
Electricity	90	---	40	---	---	130
Total	1,570	4,500	300	220	470	7,110

Source: Ref. 10

Table 6. Estimated per capita use of energy in rural areas of seven developing countries

	India*	China, Hunan**	Tanzania**	Northern Nigeria** 10^3 kcal/day	Northern Mexico**	Bolivia**	Bangladesh***
Human Labor	.67	.64	.64	.61	.75	.71	.67
Animal Work	1.00	.92	---	.13	1.30	1.83	1.00
Fuel Wood	2.86		15.07	10.27	9.70	22.83	.93
Crop Residues	1.16	13.69					1.65
Dung	.67						.57
Total Non-commercial	6.36	15.25	15.71	11.01	11.75	25.37	4.82
Coal, Oil, Gas and Electricity	.53	2.05	---	.02	19.81	---	.27
Chemical Fertilizers	.22	.34	---	.05	5.33	---	.10
Total Commercial	.75	2.39	---	.07	25.14	---	.37
Total All Sources	7.11	17.64	15.71	11.08	36.89	25.37	5.19

*Ref. 10

**Ref. 12

***Ref. 11

What is outstanding in Tables 4 and 5 is not just the fact that an average U.S. citizen consumes 25 times as much energy as does a peasant in India but also the difference in the spending patterns. A full 1/3 of the energy in the U.S. is spent in transportation and another 1/3 in industrial activities, items that are negligible in a village. In contrast, agriculture and domestic activities account for 85% of the energy spent in the village, items that account for only 25% of the energy used in the U.S. Cooking by itself represents 61% of the total in the villages while in the U.S. this item represents less than 1.5%.

Between these two extremes one has "islands of prosperity" represented by 10 to 20% of the urban affluent part of the population of almost all countries outside the developed industrial countries.

One has therefore quite different problems in different parts of the world and strategies to face them are bound to have many differences.

Since non-commercial sources are renewable and commercial ones, in general, are not, one immediately associates the first ones with sparsely populated rural areas (and decentralized uses) and the latter one with heavily populated urban areas and centralized solutions.

This association is not entirely justified as we will see later.

APPENDIX I

Classification of Less Developed Countries

Lower-Income Countries (annual per capita income under $200) 1972 dollars.

South Asia	Lower-Income Sub-Sahara Africa	
Afghanistan	Burundi	Niger
Bangladesh	Central African Republic	Rwanda
Burma	Chad	Sierra Leone
India	Cahomey	Somalia
Nepal	Ethiopia	Sudan
Pakistan	Guinea	Tanzania
Sri Lanka	Kenya	Togo
	Madagascar	Uganda
	Malawi	Upper Volta
	Mali	Zaire

Middle-Income Countries (annual per capita income over $200 and under $1000) 1972 dollars

East Asia	Middle-Income Sub-Sahara Africa and West Asia	Caribbean, Central and South America
Fiji	Angola	Argentina
Hong Kong	Bahrein	Barbados
Korea(South)	Cameroon	Bolivia
Malaysia	Congo P.R.	Brazil
Papua New Guinea	Cyprus	Chile
Phillippines	Egypt	Colombia
Singapore	Ghana	Costa Rica
Taiwan	Israel	Dominican Republic
Thailand	Ivory Coast	El Salvador
	Jordon	Guatemala
	Lebanon	Guyana
	Liberia	Haiti
	Mauritania	Honduras
	Morocco	Jamaica
	Mozambique	Mexico
	Oman	Nicaragua
	Rhodesia	Panama
	Senegal	Paraguay
	Syria	Peru
	Tunisia	Trinidad and Tobago
	Turkey	Uruguay
	Yemen AR, DM	
	Zambia	

Source: World Bank

II. SMALL SCALE DISPERSED SOLUTIONS

Big cities have large densities of people, which consume large amounts of energy "per capita", depend very heavily on the use of fossil fuels and produce large amounts of waste and pollution; most of the present technologies in use in cities are "very hard" (including the treatment of refuse and sanitation) in the sense of requiring large and bulky systems for the production and use of energy; on the other hand in rural areas, in the developing countries, the energy consumption "per capita" is much smaller.

As can be seen in Table 7, energy consumption "per capita" in cities does not change much all over the world. The energy consumption in rural areas in India and Brazil however is more than 10 times smaller on a "per capita" basis than in most cities.

In addition to that the energy consumption density (watt/m^2) in urban areas is also pretty much the same in most countries; in rural areas this density is more than 100 times smaller than in cities.

The association of "renewable" "small scale" and "decentralized" is a fairly natural one because direct solar energy has such low density (~ 100 w/m^2); biomass, hydropower and wind have even lower densities (Table 8).

Table 7. Urban and Rural Densities

Country	Pop. Density (people/km^2)		Energy Consumption (kcal/cap./day)		Energy consumption density watt/m^2	
	Urban	Rural	Urban	Rural	Urban	Rural
INDIA	6,000	135	41,600	7,200	12	0.04
NEW YORK	560	-	238,000	-	6.4	-
LONDON	1,100	-	108,000	-	5.7	-
TOKYO	980	-	81,000	-	3.8	-
S.PAULO (BRAZIL)	1,260	13	26,000	9,600	1.6	0.006

1 kw of installed power corresponds to a consumption of 20,800 kcal/day.

Table 8. Energy Densities

Source	watts/m^2
Wind (North Seacost)	~ 4.5
Fuelwood plantation	~ 1
OTEC (tropical oceans)	~ 0,8
Wind (continents)	~ 0,6
Fuelwood (natural forests)	~ 0,2
Biogas	~ 0,18
Hydropower	~ 0,02

The idea is therefore to use solar energy as it comes in small dispersed quantities that do not require much processing ("soft"technologies). The attraction of a long lost bucolic rural life exerts of course a strong attraction in the minds of many proponents of this "soft path".

We will discuss and evaluate here a number of the technologies used to supply energy from decentralized sources:

1. Biogas production
2. Minihydroelectric stations
3. Direct solar collectors
4. Photovoltaics
5. Wind

1. Biogas Production

The production of gas by anaerobic conversion of biomass is one of the most promising methods for the solution of the energy problems of villages of the undeveloped world.

The process is quite simple, in principle[13,14,15]: animal dung, pieces of vegetation (crop stalks, straw, grass clipplings and leaves), garbage and waste water are sealed up in insulated containers (digesters) and left to decompose. Digestible organic materials (liquids, proteins and most starches) are broken down by acid-producing bacteria and the resulting volatile acids are in turn converted by anaerobic methanogenic bacteria into a gas that is typically composed of 55 to 70% methane (CH_4), 30 to 45% of carbon dioxide (CO_2) and a trace of hydrogen sulfide and nitrogen. Besides the versatile low-pressure, medium-caloric gas (between 5,300 and 6,300 kcal per cubic meter) the process yields an organic fertilizer of outstanding quality and improves sanitation conditions in rural areas. (Figure 4)

With the help of minor modifications the biogas can be used to power internal combustion engines and to substitute for diesel oil in small electricity generators for lighting and irrigation.

The burning of biogas for cooking is clearly advantageous when compared to the burning of animal manure. Typically the efficiency of biogas digesters is 60%, which means that 1 kg of dry manure produces 400 liters of gas with an energy content of 2,200 kcal; if the cooking efficiency of this gas is 50%, 1,100 kcal will be delivered to the cooking pan.

If 1 kg of dry manure having an energy content of 4,000 kcal/kg (which is probably an overestimate) is burned directly for cooking the amount of heat delivered to the cooking pan will be 400 kcal in a cooking stove that is 10% efficient. Biogas is therefore 2.5 times more efficient than manure for cooking purposes.

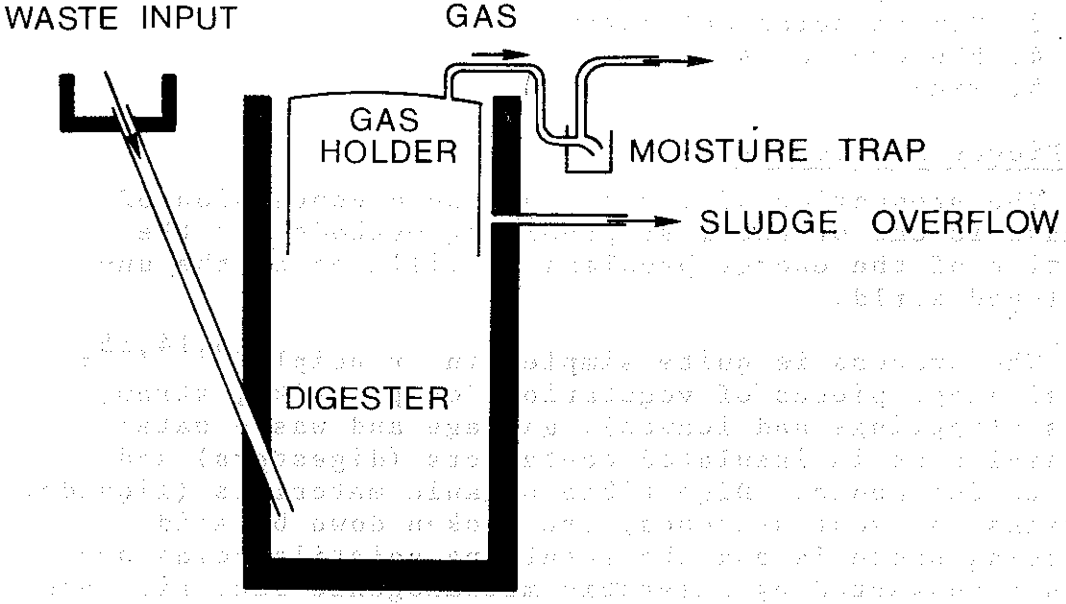

Fig. 4 - Biogas plant schematics

The method was introduced in China some years ago but picked up momentum only in the last 5 years with 410,000 digesters in use in Szechwan province alone and another 80,000 in Mien-yang country in 1975. Hundreds of thousands of households benefitted from them.[16] It is reported that in the first 6 months of 1976 another 1.3 million digesters were built in China.[17]

The main problem of biogas conversion is that it does not work in cold regions because of the thermal requirements of the fermentation process. In addition to that the pH of the mixture has to be watched and a minimum of maintenance given to the pits.

An estimate made of the potential for biogas generation in China[16] (based on the residues of cattle, horses, pigs, chickens and man) is the energy equivalent of 48 million tons of coal per year (more than 15% of the total consumption of energy in that country). A similar estimate for India[18] gave 60 million tons of coal - enough to satisfy all the rural domestic requirements of energy for the country.

The widespread introduction of biogas generation seems therefore to be feasible in many undeveloped areas of the world.*

2. Minihydroelectric Stations

The technology for generation of hydroelectric power from small stations has been available for many years but its use has always been dwarfed by the construction of gigantic dams and huge hydroelectric power projects.

The definition of minihydroelectric plants is not very clear: in this category one includes, in general, dams less than 100 feet in height, less than 10,000 acre-foot of reservoir storage capacity and with a potential

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*It is intriguing to observe that biogasefiers have become quite popular in China and are facing many institutional difficulties in India. This is not due to political inducement in China, as one might think. According to Vaclav Smil (private communication) the Chinese farmers use the dung of their domestic animals (pigs and chickens) in their private lots to run the digesters. Community plants on the commune level are rare in China.
In India the cultural habits are such that cattle roam around the country making it difficult to collect their dung.

capacity less than 5,000 kilowatts[19]. A dam with 10,000 acre-foot in storage capacity and a height of 100 feet corresponds to a potential of 5,000 kw.

There are almost 50,000 of these dams in the United States with a total capacity of 27,000 Megawatts, i.e., an average of 500 kw per site (Table 9). These dams, if used, could increase by almost 50% the present US hydroelectric capacity of 65,000 Mw.

It might be interesting to point out that from Table 9 one can estimate what is the amount of power distributed in small dams as a function of their average size.

It results that the total power available (P) on dams of power E is

$$P \sim E^{1/2}$$

i.e. the total power available increases slowly with the size of the dam indicating the substantial amount of power dispersed in small dams (Figure 5).

A massive effort to build mini-hydrostations was made in China[16] and by the end of 1975 over 40,000 of these stations (with an average capacity of 50 kw) were in operation. Since China does not have a very large installed hydropower capacity (~ 10,000 Mw in 1975) the contribution of ministations to the total hydropower is appreciable.

Table 9. Number of Existing Dams Sorted by Height and Storage Characteristics in the United States

Maximum height (feet)	Maximum Storage (acre-foot)			
	0-99	100-999	1,000-9999	>10.000
0-19	12,432	7,009	1,262	398
20-49	12,883	8,332	1,789	433
50-99	429	919	574	519
>100	100	91	140	602

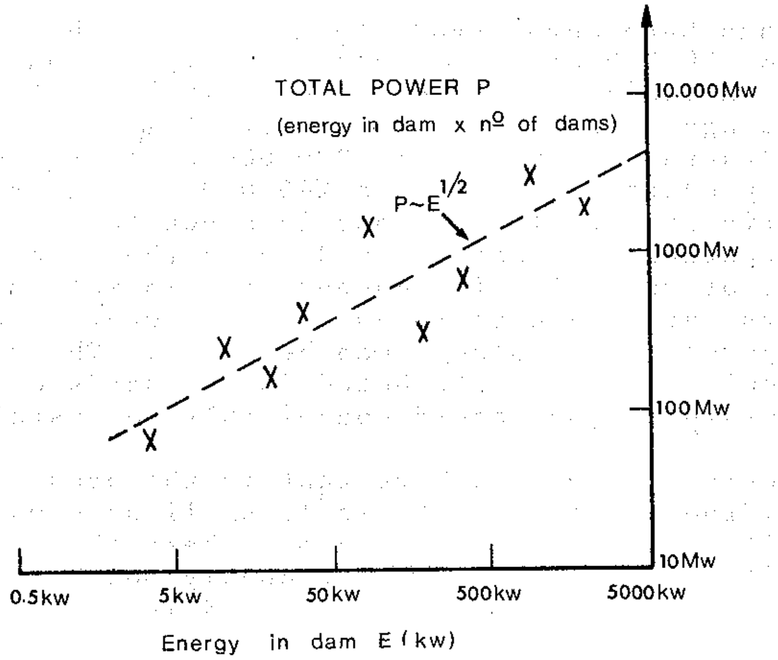

Fig. 5 - Total power available "versus" the average size of small dams.

A 100 kw minihydroelectric plant, enough to supply the needs of at least 100 houses, can be installed in a small waterfall with a flow of 1.5 m^3/sec and a 6 meter head. If smaller heads are available but the streams are swift moving, one can still operate small turbines with good efficiency. Since the available mechanical energy in a flow of water is $gh + 1/2\ v^2$ per kilogram (h is the head, v the velocity and g the gravity acceleration, 9.8 m/sec^2), a stream with velocity of 10m/sec is equivalent to a 6 m mead waterfall.

The price per kilowatt of installed capacity is competitive with large conventional hydroelectric stations.[20]

Measurements (or even good estimates) of the hydroelectric potential of small rivers and streams in general do not exist around the world. Rough estimates can be made on the basis of precipitation over a given region, and the region's average altitude above sea level. The product of these two numbers is a crude measure of the total hydroelectric power available.

Using this relationship the total hydropower potential of a country like Brazil can be estimated from knowledge of the potential in a region like Europe, where the potential has been more carefully measured. The area of Brazil is 8,500,000 km^2, the annual precipitation of water 2000 mm (which corresponds to 15×10^{12} m^3 of water) and the average altitude of the country 400 m. The product of these two numbers is 800,000 while the corresponding product for Europe is 240,000. Since the hydroelectric potential of Europe is known to be 158,000 Mw, the potential in Brazil should be on the order of 500,000 Mw, of which 1/3 is concentrated in well known large rivers where waterfalls do exist or where conventional large hydroelectric plants can be built. The remaining 2/3 should then be distributed in thousands of streams where minihydrostations could conceivably be installed.

It should be stressed here that in the usual tabulations of hydroelectric potentials[21], small streams are ignored; it is difficult to find out where the line is drawn in different countries but probably most resources below 5,000 kw per site are not included in these estimates.

3. Direct Solar Collectors

Flat plate collectors are the simplest of all methods for collecting the sun's energy and heating up water for domestic (or industrial uses).

The solar rays go through two transparent glass plates and are absorbed in a darkened metal surface to which are attached pipes conducting water which is therefore heated up. (Figure 6) The double layer of glass plates with a layer of air between them (which is transparent to the incoming radiation) acts as a thermal insulator trapping therefore the infrared radiation inside the collector; this is the well known "green-house effect" used all over the world in cold climates to grow vegetables or flowers in the winter.

The efficiency of conversion of the incident radiation into heat (carried away by the water) is approximately 50% and it is possible to produce hot water in the range 40-90°C.

A typical insolation in tropical regions is 4,000 $kcal/m^2/day$ (~ 0.5 $cal/m^2/min$). If all this heat could be captured usefully it could replace the consumption of approximately 0.5 liter of oil*.

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* 1 liter of oil = 9×10^6 cal.

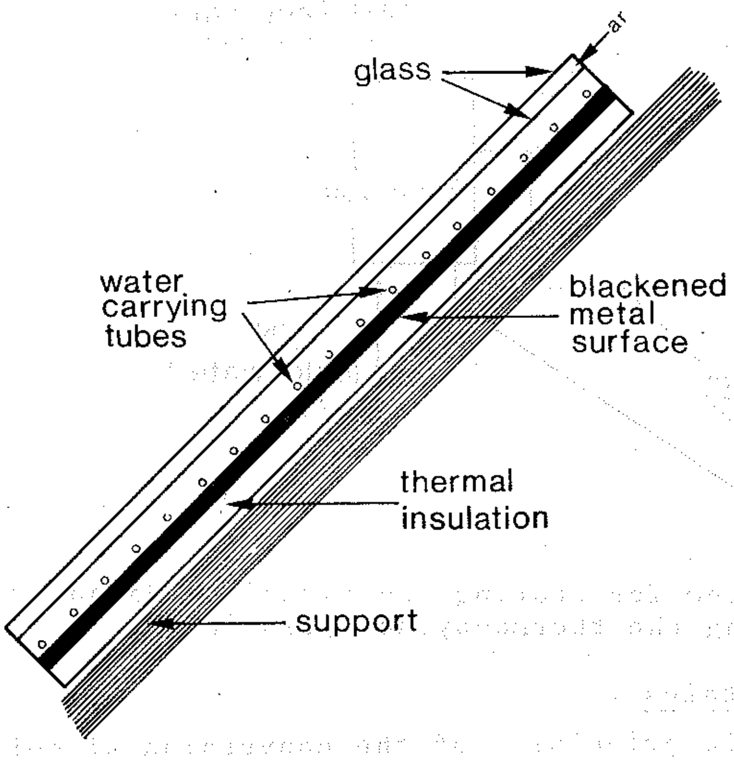

Fig. 6 - Flat plate collector

In practice a collector of 4 m^2 can supply 300 liters of water at 40-60°C which is needed for domestic uses for a typical family.

Systems in use have a reservoir for the hot water in which water is driven by the thermo-syphon principle. (Figure 7)

Hundreds of thousands of residential solar collectors are in use in many countries around the world, mainly Israel, Japan and the United States.

The technology is simple enough to be used in many LDC's based on local manufacturing facilities.

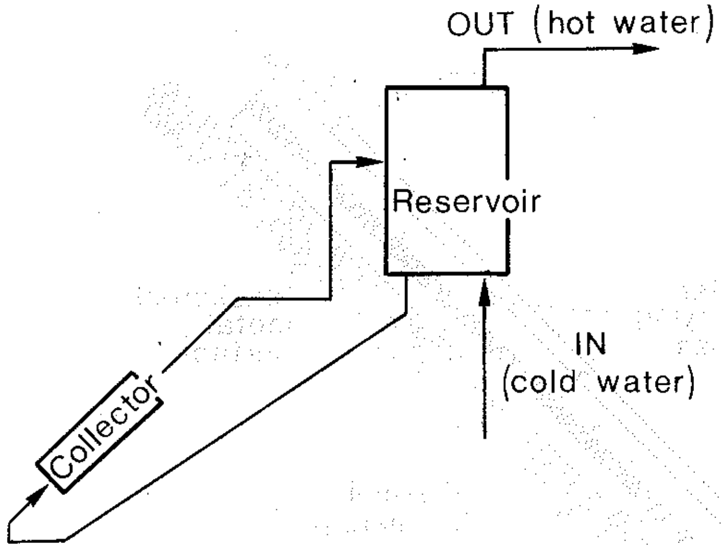

Fig. 7 - System for storing and distributing hot water using the thermo-syphon principle.

4. Photovoltaics

The basic principles of the conversion of solar energy into electricity are well known and the characteristics of a typical solar cell[22] are shown in Figure 8.

Typical maximum efficiencies are of the order of 10% and typical insolation in a tropical country such as Brazil[23] can be seen in Figure 9.

The strong variations of solar insolation from day to day and the fact that the sun shines only during the day end up by establishing severe limitations in the use of photovoltaic cells except in satellites.

In practical applications on the earth's surface the average yearly solar intensity can be considered as 100-200 w/m^2 which is not very high. Therefore large surfaces covered by photocells are needed with corresponding high costs (15,000 dollars per peak kilowatt).

Most of the present applications of photovoltaic cells (except on satellites) are being made in special isolated situations which justify the high costs such as isolated telecomunications relays, educational TV in remote sites, power for medical dispensaries and in some cases water pumping for animal and human consumption.

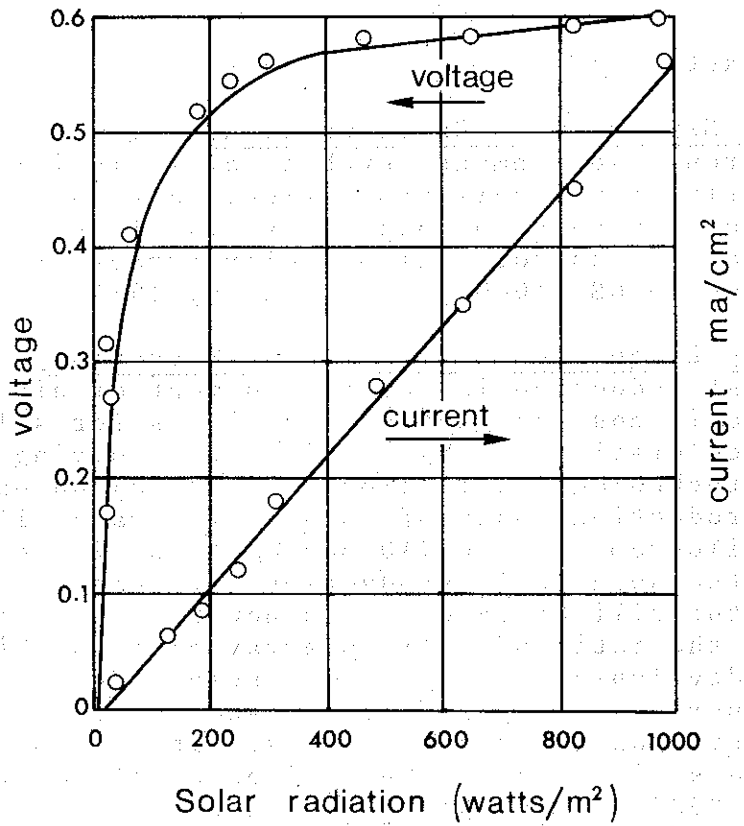

Fig. 8 - Electric characteristics of a typical photovoltaic cell

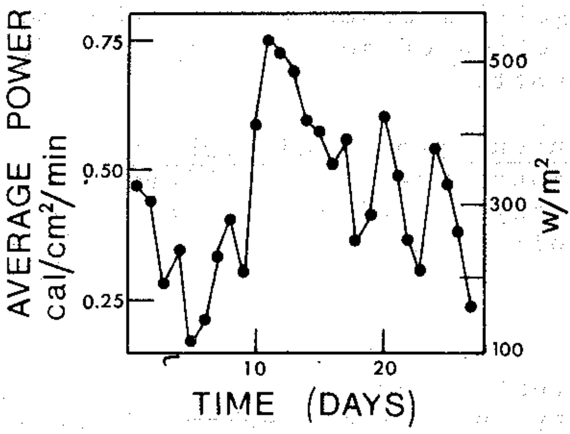

Fig. 9 - Typical insolation in São Paulo, Brazil

Undoubtely photocells would find broad commercial applications if costs were reduced to US $100 - US $300 per peak kilowatt.

The US Government expects this to happen in the middle of this decade as the result of a combination of the following actions:[24]

1. Market Expansion of Existing Technology: Market stimulation through government purchase of a significant fraction of early annual cell production. A total United States government purchase of approximately 11 MW through 1983 is planned. Costs for silicon solar arrays are expected to drop to US $1000 per peak kW by 1984.

2. Develop Large Area Silicon Sheet Technology: One approach to cost reduction is the development of high capacity, low unit cost production techniques for silicon cells. The acceleration of this activity, involving silicon sheet technology, will provide for: (a) an early reduction in production costs of solar cell grade silicon from $65 per kilogram (kg) to $10 per kg; (b) increased efficiency of the solar cell production fabrication (over 75 percent of the silicon material is now wasted); (c) improvement in the ratio of cell to array area (packing factor); (d) development of suitable encapsulation materials to increase array lifetime; and (e) automated production of silicon solar cell arrays. It is expected that this process will reduce the silicon-based solar cell array costs to $500 or less per peak kilowatt.

3. Conduct Thin Film and Novel Materials Research: Use of thin film deposition techniques utilizing silicon, cadmium sulphide, gallium arsenide and other materials may allow the production of solar arrays costing $100 - $300 per peak kilowatt.

4. Develop Concentrators and High Intensity Solar Cells: The use of concentrators, combined with cells from low-cost silicon arrays costing $500 per peak kW, should lead to combined collector/cell costs of $250 per peak kilowatt by 1986.

5. Wind

Although apparently very erratic, the average value of the wind velocity in a given region of the Earth is reasonably constant; in general the monthly average velocity does not show deviations greater than 10 or 15% of the annual average.

The use of wind was very important in past centuries as is well known mainly in the western coastal regions of Europe[25].

In more recent times the farm wind rotor made of metal blades was very important for water pumping in many regions around the world and the intermitent generation of electricity.

Recent modern designs such as the Darrieus and Savonius as well as better aerodynamical designs of old models are in intense investigation in many laboratories around the world.

One can derive a theoretical expression[26] for the maximum power (P_{max}) of rotors as being

$$P_{max} = \left(\frac{8}{27}\right) \pi r^2 \rho v_i^3$$

r - radius of rotor
ρ - density of the air
v_i - incident velocity of the wind

Table 10 shows P_{max} for a variety of wind velocities and radius of rotors.

As can be seen from this Table a wind of 10 mph can supply approximately ~ 30 watts/m^2.

Wind energy has the inherent character of supplying mechanical (or electrical) power for intermittent chores; this means that storage might be indispensable for some purposes such as the use of wind power for lighting or refrigeration. The economics of wind power seems to be competitive in many cases, in isolated locations.

There is much discussion of interlinking many wind power electric generators such as to smooth out the intermitency of the winds without the recourse of large storage capacities but no definite plans for such ventures have been established.

Table 10. Theoretical power of several rotors

Wind speed (mph)	Power (kw)			
	r = 3,3 m	r = 8,3 m	r = 16,5 m	r = 33 m
10	1	6	25	100
20	8	50	200	800
30	27	169	675	2700
40	64	400	1600	6400
50	125	781	3125	12000
60	216	1350	5400	21600

III. LARGE SCALE CENTRALIZED SOLUTIONS

The counterpart of the idea of using decentralized energy sources to supply the needs of rural areas is the generation of electricity in large hydroelectric dams or nuclear reactors i.e. in a centralized way to feed large cities where consumption is concentrated.

1. Hydroelectric Power

The world hydroelectric resources are shown in Fig. 10 and can be seen to be very large (2,200,000 Mw of generating capacity at 50% capacity factor). Most of this potential is located in LDC's where the operating capacity is presently less than 10% of the total[27].

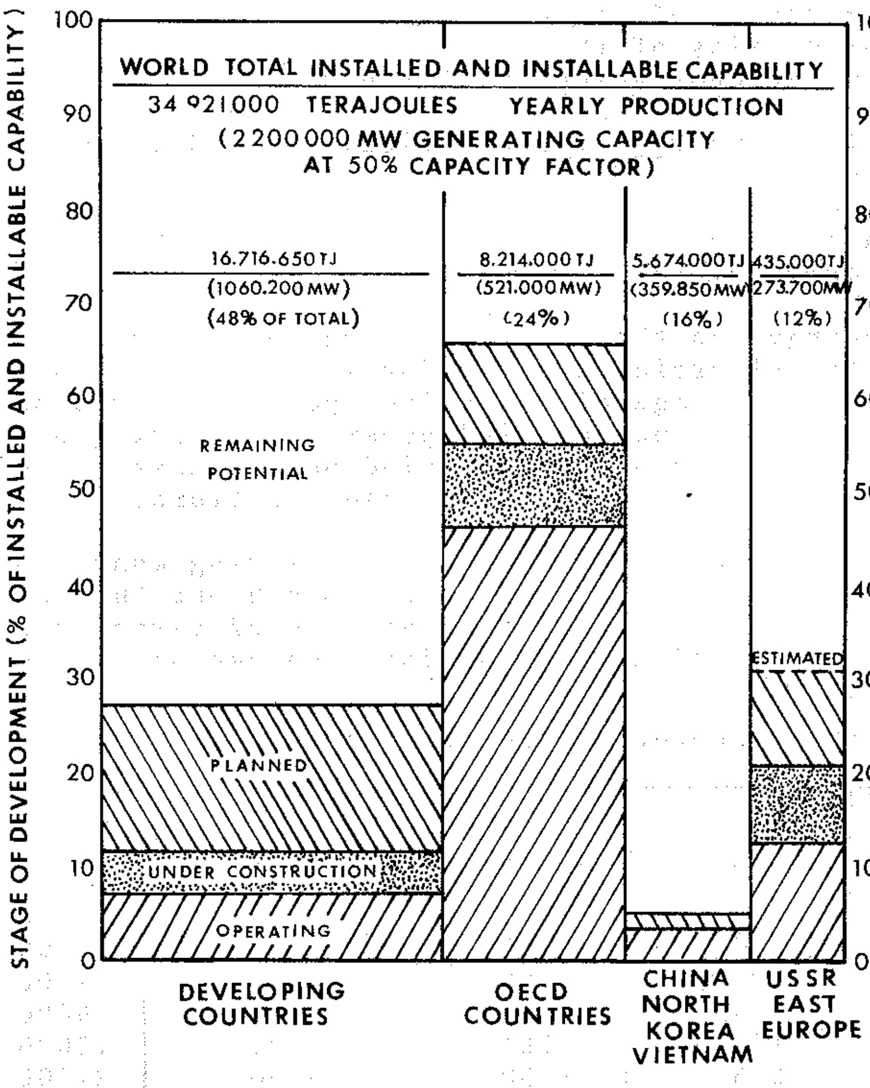

Fig. 10

The annual fossil fuel equivalent energy potential from the 1,800 Gw of hydroelectric capacity located in LDC's (counting 1 unit of electricity as being equivalent to 3 units of fossil fuel energy) is 115 Quads (with an average capacity factor of 63% which is the number for 1975). Considerably less electricity will be needed by LDC's before the year 2000.

Because of the inherent need for chemical fuels (for transportation and some industrial applications) there is a practical limit to the degree of electrification a country can reach as seen in Figure 11.

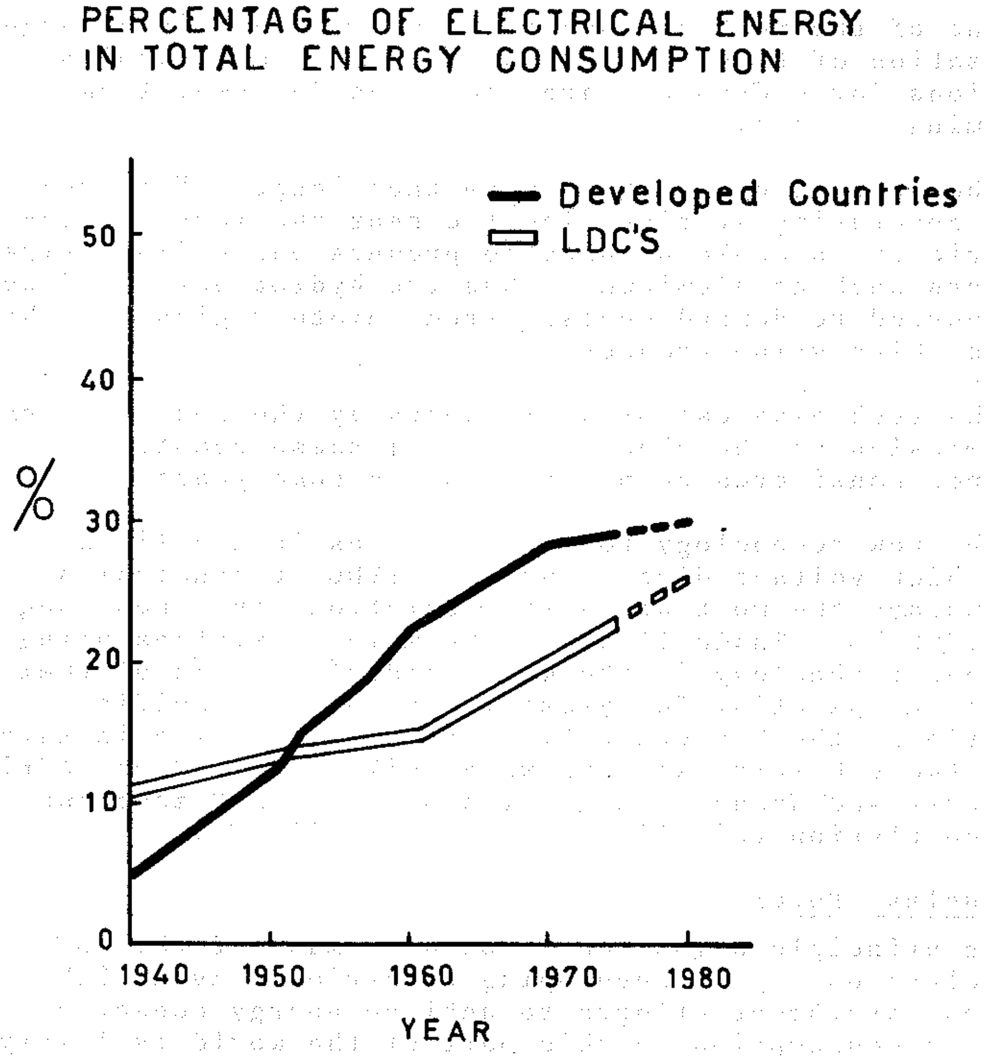

Fig. 11

In 1972 electricity accounted for 28% of the energy consumption in the United States and 20% of the LDC's; it has been estimated[28] that these numbers will rise to 35 and 25% respectively by the year 2000. The degree of electrification of LDC's will probably be limited in the next 25 years mainly by the rate at which plants can be built and by capital available.

The world hydropotential is actually larger than the figures given in Figure 10; not included in the numbers given are waterfalls or dams (existing or to be built) of less than a 100 feet head and a hydro potential smaller than 5 Mw as discussed in the previous chapter.

One of the most serious problems involved in a larger utilization of these potentials is that the convenient locations for hydropower are sometimes far away from consuming centers.

The suggestion has been made that "captive" hydropower generating stations located near the large hydroelectric sites could be used to produce energy intensive products such as aluminum. Thus the hydropower could be transported to demand centers from remote regions in the form of high value products.

The technological problems posed by the long distance transmission of the electricity from these remote areas were not considered completely solved some years ago.

The new technology to reduce losses in the lines using high voltage direct current (HVDC) transmission is nowadays the most attractive solution for lines longer than 1000 km. Table 11 shows the main facilities using this new technology in the world today[29]; some of them have been operating for years including the Pacific Intertie in the Western U.S.. One should notice in this table the Cabora-Bassa line which will supply South Africa (Pretoria and Johannesburg) with power from Mozambique. Upon completion this line will carry 3,600 Mw.

2. Nuclear Power

In principle a good case could be made of the role of nuclear energy in developing countries. Even with the most stringent efforts to achieve energy conservation the consumption in this part of the world is likely to increase from the present 61 Quads to at least 160 Quads by the end of the century[30].

Table 11. High Voltage Direct Current (HVDC) Systems

	Transmission Distance (km)	Rated Voltage (kv)	Rated Power (Mw)	Commissioning
		In Service		
Volgograd-Donbass (USSR)	470	±400	720	1962-65
New Zeland	570	±250	600	1965
Pacific Intertie (USA)	1362	±400	1440	1970
Nelson River, Bipol 1 (Canada)	895	±300	1080	1973
Inga-Shaba (Zaire)	1700	±500	560	1976
		In Construction		
Cabora Bassa (Mozambique -South Africa)	1414	±533	1920	1979
Nelson River, Bipol 2 (Canada)	895	±500	1800	1981-82
		Under Active Consideration		
Gull Island (Canada)	750/1080	±400	1600	1985
Nelson River, Bipol 3 (Canada)	900	±500	1800	1983-85
Ekibastus Centre (USSR)	2400	±750	6000	?

The uneven distribution of oil, gas and coal reserves around the world does not particularly benefit many LDC's (with the exception of OPEC countries) and by year 2000 will put some of these countries in a position of increasing dependence on energy imports.

Against this background the role of nuclear power in LDC's could be visualized as two-fold:

a. it could offer a substitute for oil and gas (and possibly coal) which would otherwise be required for electricity production and a means of avoiding an overwhelming dependence on imports.

b. it is a technologically mature solution.

The word substitution in item a above is used in the sense of being economically competitive and after the 1973 crisis it seemed to many people that nuclear energy would really "take off" both in developed and less developed countries.

However what was witnessed in the last few years was a clear decrease of the expected role of nuclear power: the projections of the International Atomic Energy Agency (IAEA) for the nuclear capacity installed in LDC's in the year 2000 made in 1977[31] were about half of the estimates made in early 1974[32]. As we will show below more realistic projections are even lower reducing drastically the role to be played by nuclear energy in LDC's.

The usual reasons given for the downward revisions of nuclear power in LDC's are the following[31]:

1. the diminished growth in electrical demand that has occurred in many countries during the last several years.
2. the extremely high cost of nuclear plant construction, which has placed financial burdens on countries with existing nuclear programmes.
3. the present lack of commercially available small and medium power reactors, which many of the smaller states would need in order to expand their electric power systems and
4. the growing awareness of LDC's that more attention should be paid to exploitation of indigenous energy sources.

A point seldom discussed in the IAEA (and other papers on the subject) is the question of technology transfer and the perception of the leaderships of LDC's of this problem. The appropriation of modern technology (and particularly of the nuclear technology) is seen as key to development in most of the developing world for the following reasons:

A. On the one hand, due to imitative tendencies, the rising middle class in LDC's favours strongly the adoption of the consuming patterns of more developed countries. In small countries this is done through imports (and trade) but in the larger ones the local production of many goods is necessary. National policies furthering import substitution are in effect in most of the more prosperous LDC's.

B. On the other hand some military, and more generally the nationalistic civil elements of society, do not want to remain as secondary "clients" of the larger industrial nations (United States and Soviet Union, in general) and want to achieve national independence on all fronts due to economic, political and strategical reasons. The more advanced they are, the more uneasy is the relationship between the "client" and "patron" state as the governments of LDC's become more assertive. This can be clearly seen in the case of the Non Proliferation Treaty which is considered discriminatory and has not been signed by the more advanced LDC's.

On the surface these arguments would seem to play in favour of a larger role of nuclear energy in LDC's; in practice the opposite has happened because technological transfer of nuclear technology has been rather unsuccessful in most cases.

Table 12 shows the present nuclear and conventional electrical capacities of 20 LDC's and the projected nuclear power forecast for year 1990, made in 1975.

As can be seen in this Table, 7 countries (Argentina, Brazil, India, Iran, Korea, Mexico and Taiwan) account for nearly 70% of the total projected nuclear capacity. The main reason for this is that all nuclear reactors manufactured at present have rather large capacities (~ 600 Mw) and a sizable electric grid is needed to accomodate them; this is the case of the 7 countries listed above.

The 4 countries with the largest nuclear programs (as of 1975) were India, Brazil, Mexico and Iran.

Although the downward revision of the Brazilian nuclear program has been the most discussed in recent litterature it is quite obvious that the nuclear programs of Iran, India, Mexico are also being phased out.

In Iran even before the downfall of the Shah the program was under heavy criticism due to a lack of infrastructure and economics. Under iranian conditions the use of gas for the production of electricity made much more sense than electricity.

In India a much larger emphasis on coal has reduced the importance of nuclear power and in Mexico the recently found oil deposits have dimmed prospects for nuclear energy.

Table 12. Nuclear and Conventional Electric Capacities in LDC's x 10^3 Mw

	Nuclear*	Electrical**			Nuclear Power Forecasts***
		Hydro	Thermal	Total	1990
India	1.689	9.029	14.020	23.689	31.4
Brazil	3.116	18.411	3.385	21.796	11.4
Mexico	1.308	4.691	8.156	12.847	21.6
Argentina	1.505	1.745	7.771	9.856	8.1
Iran	8.982	0.804	4.326	5.130	10
Taiwan	3.800	8.000	32.000	40.000	10.3
Venezuela	-	2.245	2.931	5.176	4.4
Korea	3.598	0.711	4.629	5.340	9.8
Turkey	0.620	1.873	2.477	4.350	5
Colombia	-	2.420	1.430	3.850	1.2
Pakistan	0.126	0.867	1.232	2.236	4.9
Egypt	-	2.500	1.400	3.900	5
Thailand	0.600	0.910	1.865	2.775	1.8
Peru	-	1.500	1.055	2.555	-
Philippines	0.621	1.138	2.369	3.507	4.8
Hong Kong	-	-	2.919	2.919	-
Chile	-	1.462	1.199	2.661	-
Singapore	-	-	1.390	1.390	0.6
Indonesia	-	0.450	0.810	1.260	-
Bangladesh	-	0.110	0.840	0.950	-
Total	25.965	58.866	96.164	156.187	132.1

*Power reactors operating, in construction or ordered as of june 1978.

**1976 UN Statistical Yearbook.

***Source: LDC's Nuclear Power Prospects 1975-1990: Commercial, Economic and Security Implications. Richard J. Barber Associates (1975).
All units below 600 Mw removed.

On the basis of this information we assumed that the nuclear programs of these 4 countries will simply stagnate at their present levels, i.e. that no new projects will be implemented. Taken together with the data of Table 12 this leads to the point labeled "stagnation hypothesis" in Figure 12 (less than 40,000 Mw of installed capacity in 1990).

In the light of the above discussion one could add the following arguments to the 4 points listed by Lane et al[31] to explain the decrease of nuclear power forecasts in LDC's.

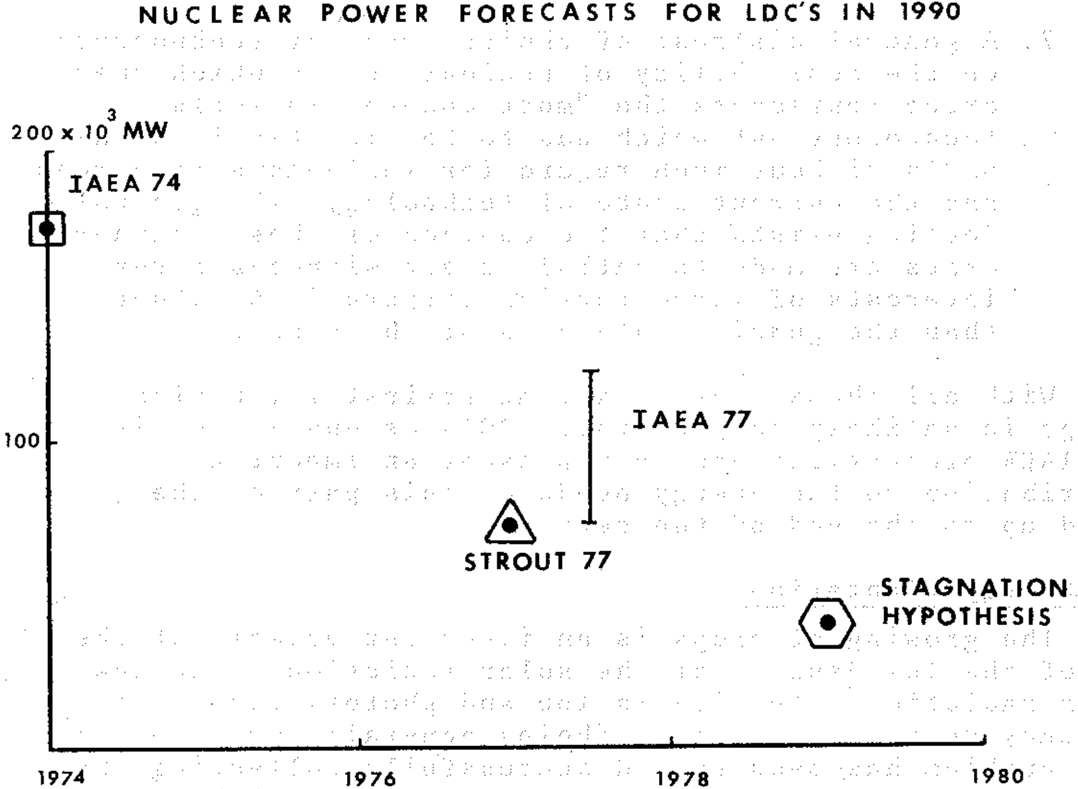

Fig. 12

5. The realization by LDC's that the introduction of nuclear energy is not followed by the transfer of technology desired by most countries. Nuclear power increases political and technological dependence rather than the opposite.

6. A small but growing awareness of the risks of nuclear energy as far as accidents and offenses to the environment are concerned. This awareness becomes the more important the wealthier the country (or the particular region where the reactors are located). The recent accident at the Three Mile Island reactor in Pennsylvania, US, dramatized this problem in a particularly

clear way. Since a complete meltdown could occur in the US with all its experience and trained personnel, how would such situation be faced in a LDC much less prepared for it?

7. A general distrust of choices made by technocrats on the desirability of nuclear energy which they argue represents the "most modern" in world technology but which has to be imported into the LDC's without much regard for indigenous resources and the current state of technology. The general feeling exists that the choices of these technocrats are made to satisfy their wishes and the interests of large foreign corporations rather than the genuine interests of the country.

With all these factors acting against it, nuclear energy is unlikely to penetrate LDC's as envisioned in the IAEA projections and to represent an important contribution to the energy needs of this part of the world up to the end of the century.

3. Energy Plantations

The growing of crops is an important example of the use of the low density of the solar radiation. Although solar radiation intensity is low and photosynthetic efficiency does not exceed 5% (being generally much lower) this problem has been solved successfully collecting the product of photosynthesis over large areas. The harvesting of crops (or harvesting the solar radiation) allows one to feed the millions of people in a city with the product of a few thousands of hectares around the city.

Table 13 shows typical productivities of agricultural products in Brazil; as a rule of thumb 1 ha produces the food needed per inhabitant.

The same is approximately true for the production of liquid fuels from energy plantations.

Two main routes are being followed in this direction: the production of ethanol and methanol which are good substitutes for gasoline and other liquid carburants as can be seen in Table 14.

Table 13. Agricultural Productivities in Brazil

CROP	Yield (tons/ha)
Rice (non irrigated)	1 - 2
Rice (irrigated)	2 - 4
Black beans	0.8 - 1.5
Soyabeans	1.5 - 2.0
Corn	1.5 - 3.0
Wheat (non irrigated)	0.8 - 2.0
Wheat (irrigated)	1.0 - 2.5
Coffee	1.5 - 2.0

Table 14. Densities and Energy Content of Carburants

	Density (kg/liter)	Calorific content (kcal/kg)	kcal/liter
Gasoline	0.734	11,100	8,150
Ethanol	0.789	6,400	5,040
Methanol	0.796	4,700	3,740
Wood	0.400	2,524	1,010
Charcoal	0.28-0.44	6,798	1,980-3,000

Although the calorific content of ethanol and methanol are lower than gasoline they are superior fuels in octanes which compensates this to a large extent; on a volume basis a car running on ethanol or methanol uses approximately the same amount of any of these fuels.

For mixtures up to 20% ethanol or methanol in gasoline no modifications in the motors are needed but the use of pure fuels requires extensive modifications. This is being done to a significant extent in Brazil; 1/4 of all cars manufactured in the country (250,000 per year) will run on pure ethanol starting this year and all cars presently run on a mixture of 20% alcohol and 80% gasoline.[33]

The production of ethanol from sugar cane is a well established technology and this is the crop being used extensively; presently 50,000 barrels per day are being produced with plans to reach 200,000 bpd in 1985; since 1 hectare of land produces 3,500 liters of ethanol per year* approximately 4 million hectares of good land will be needed** (5% of the arable land in use in Brazil at this time).

Additional expansion of the program will be made using eucalyptus from reforestation projects which allow the use of marginal lands.

The celulosic chains in wood can be broken by the action of sulphuric acid (acid hydrolisis process or by enzymatic methods) leading to sugars that can be converted into alcohol.

The economics of these processes is such that the barrel of ethanol costs between 30 and 40 dollars which is marginally competitive with imported petroleum. Other advantages are of course energy independence and saving of foreign exchange.

What are the possibilities of relying in energy plantations around the world?

Table 15 gives the total and arable land areas of the world.[34]

Table 15. Distribution of arable land

	Land area (10^6 ha)			Insolation
	Forest	Crops	Total	watts/m^2
Industrialized nations	1,900	.700	5,500	165
L D C's	2,300	.800	7,400	223
	4,200	1,500	12,900	

---

*An automobile consumes per year approximately 3000 liters of alcohol which means that 1 ha of land can supply the energy needs of a family.

**The production of 1 Quad of energy (10^{15} BTU=252×10^{15} cal) would require approximately 12 million ha, i.e. 120,000 square km of land.

To produce all the energy needed in LDC's from biomass would require 1/2 of the arable lands or 18% of the forested area. These are very large areas and it is unlikely that they will be used for energy purposes in the foreseeable future; problems to be considered are conflicts with food and traditional forest industries.

There is however a considerable energy potential in crop residues; at least 16 Quads/year are available from this source in LDC's.

In addition to that one should point out that at present only 11% of the world's forest increment in LDC's is being used[34] (2% for industry and 9% for fuelwood). In terms of coal equivalent 3,500 x 10^6 tons of wood are therefore lost every year (Table 16) which are equivalent to more than 100 Quads. This is more than the total present energy requirements of LDC's (61 Quads).

4. Solar Towers

The use of flat plate collectors for the utilization of the sun's energy does not permit the generation of electricity with any appreciable efficiency since the maximum temperature achievable with these collectors is smaller than 100°C, in general.

To improve the thermodynamic efficiency systems have been developed to concentrate the sun's energy incident in a large area in a single point where high temperatures can be achieved.

Table 16. Incremental Energy in Forests

	Growing stock* (10^9 m^3)	Increment (10^9 m^3)	Total Consumption (10^9 m^3)	Unused increment**	
				($x10^6$ TCE)	QUADS
Developed Countries	242	8.8	1.4	3,200	100
L D C's	382	9.0	1.0	3,500	105
Total	624	17.8	2.4	6,700	205

*Estimated to include all wood above ground
**1 TCE = 2.3 m^3 of wood

The most popular one is the "solar tower" concept in which hundreds of flat plate minors mounted on tracking devices reflect the light incident upon them in a small spacial region where high temperature steams can be produced (Figure 13).

The system works only with direct solar rays and not with the diffuse solar radiation (which is adequate for flat plate collectors).

The cost of electrical energy produced in these systems lies between 1,000 and 3,000 per kw. The need for storing systems is one of the reasons for the high cost, but they begin to look attractive in some special locations.

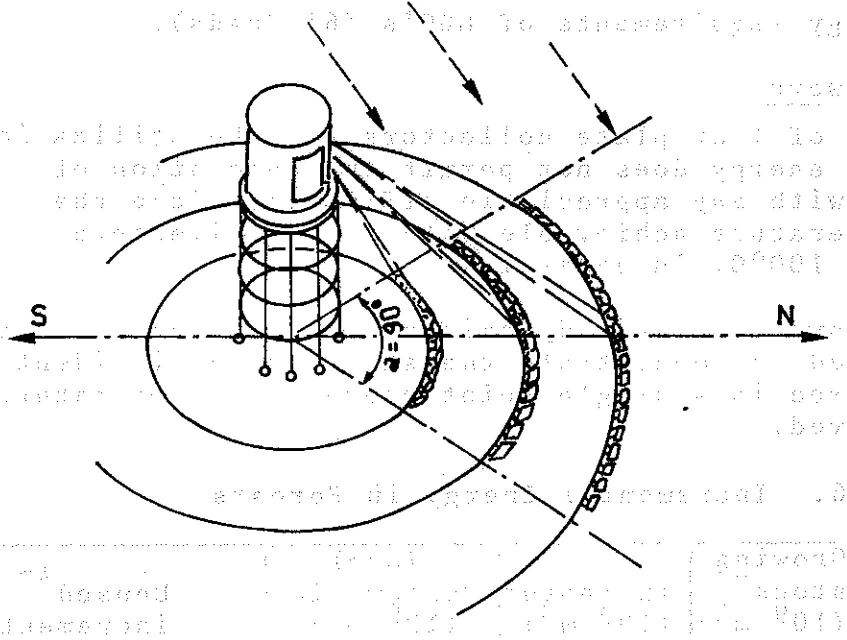

Fig. 13 - Solar Tower

IV. ENERGY CONSERVATION IN LDC's

Are energy conservation strategies of industrialized nations relevant to LDC's?

Although the "per capita" level of energy use in LDC's is in general an order of magnitude lower than in industrialized nations, most commercially sold energy in LDC's is consumed by the urban elites, who account for less than 20% of the population.

The energy consuming habits of these elites and the economic activities that sustain them are about as wasteful as those of the industrialized nations. As a consequence, much that can be said about energy conservation for affluent societies is applicable to the uses of commercial energy in LDC's.

All energy conservation experience in the industrial sector of industrialized nations is applicable to LDC's, because of the universal nature of most industrial processes and capital equipment.

The possibilities for fuel savings in industry are relatively large. This is particularly true in the case of heat recovery in industrial processes.

Table 17 shows how primary energy is used in an industrial society[35] (US) indicating that heat represents 48.5% of the total energy consumption.

Table 17. US Primary Energy Consumption

End Use	Percentage of Total
Transportation	25
Miscellaneous Electric	19.5
Feedstock and Other Nonfuel Uses	7
	51.5
Heat	
Water Heating	4
Space Conditioning	19
Industrial Process Heat	24
Cooking and Clothes Drying	1.5
	48.5
TOTAL	100.0

The spectrum of temperatures used in the german industry[36] which is quite similar to all modern industries is shown in Figure 14.

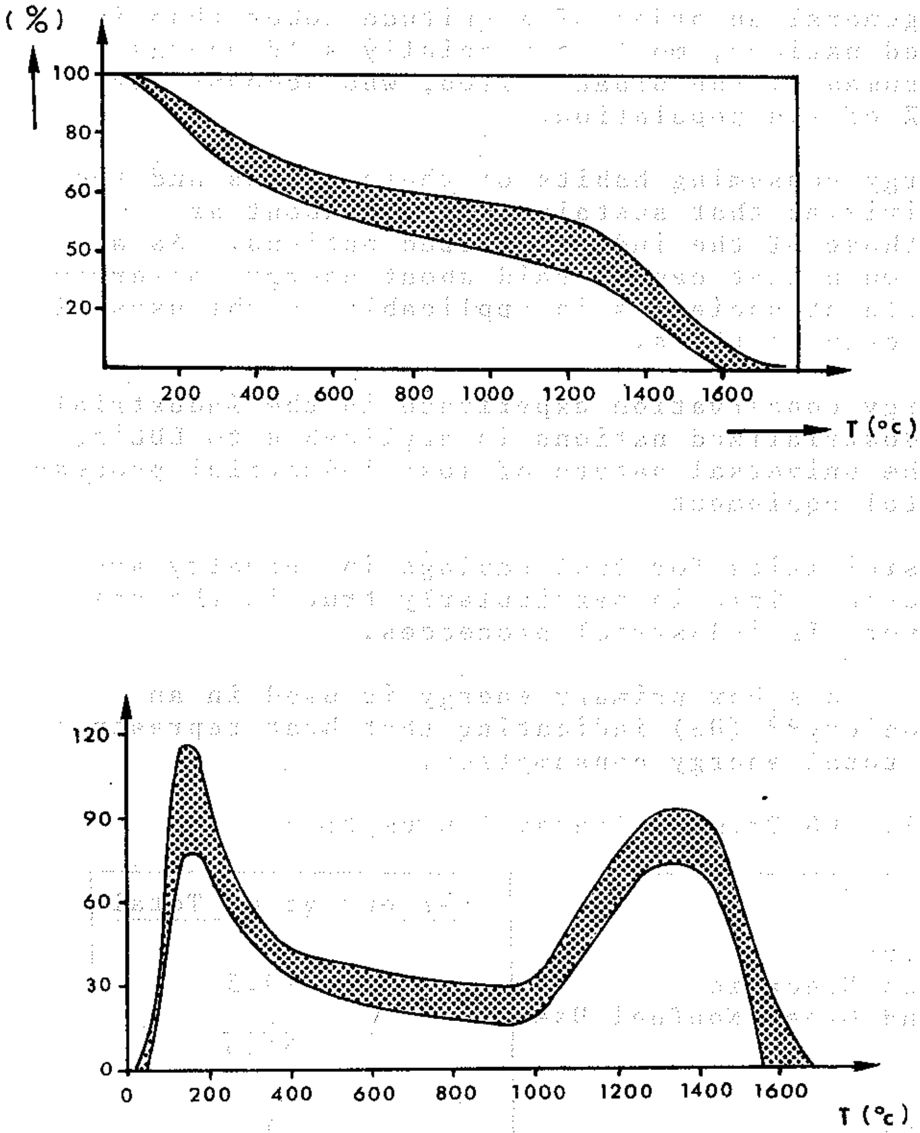

Fig. 14

What is represented in these figures is the temperature at which heat is theoretically required by the process; as one can see there is a broad peak around 1300°C and another sharper peak around 150°C.

One can estimate that 37% of the energy used in the US is in the form of hot water, low temperature industrial process heat, or space conditioning. It is clear therefore that solar heat captured in simple flat collectors or in special flat collectors with selective surfaces can represent a large share of all the heat needed in developed countries.

The problems here are not typical of developed or LDC's but common to them: any breakthrough in the US, for possible utilization in its southwestern region could work even better in tropical countries where the insolation is usually higher.

In some of the LDC's it is quite common for the government to finance (in general with low interest loans) housing complexes for workers and middle-income people. It might be quite reasonable to introduce into the design of such housing complexes, solar central heating which will add little to the initial investment and will be paid off along the years by the resultant economy of fuel or electricity. To encourage key industries to use solar heated or preheated water for steam production might also be very promising to the more widespread use of solar energy.

In the energy balance of the United States industrial boilers generating steam for processing and other low temperature heat uses represents 33% of all industrial energy consumption or 14% of total US energy requirements. The steam is produced generally at approximately 200°C from the combustion of oil, gas or coal which burn with flame temperatures of ~ 2000°C. This is an exceedingly wasteful process. It makes sense therefore to first generate electricity in a heat engine using the high temperature heat available in combustion and to recover "waste heat" for low temperature process steam applications.

Several different technologies could be used for the "cogeneration" of electricity and process steam. In general the fuel savings ranges from 20 to 30%. It has been estimated that net fuel savings from cogeneration in the US could be on the order of 2-3 million barrels of oil equivalent energy per day by the year 2000.[37]

In addition to that the following conservation measures in use in industrialized countries could be adapted to LDC's:

- Large petroleum savings are possible through the imposition of stiff fuel economy standards for new cars, which could lead to fuel savings of 50% or more.
- The use of efficient appliances (e.g.,refrigerators) and lighting practices can lead to electricity savings of 50% or more in modern residential and commercial buildings in urban centers of LDC's[38].
- Recovery of useful energy from urban refuse is becoming a mature technology in industrialized nations. These wastes can be burned directly to produce electricity and/or steam for industrial process use, or the wastes can be converted to a more convenient fuel form for use in a variety of applications. For example, pelletized urban waste could be a relatively low cost, easy to handle fuel which can be substituted for wood or charcoal. While 1 kg/day of urban waste is adequate to meet only 2% of the average "per capita" energy needs in industrialized nations, it would provide 10% of average needs in LDC's.

There are however many areas where energy conservation strategies cannot simply be borrowed from industrialized nations because of problems that are unique to LDC's:

- While there is little need for space heating in LDC's there is a need for air conditioning. Adequate air conditioning can be provided in a wide range of circumstances in LDC's without using air conditioners by simply adopting building designs appropriate for the climates of LDC's. Building practices dating back thousands of years, supplemented by some modern techniques, can be effective in keeping buildings cool without electric air conditioners.
- Biomass can substitute for costly oil in providing electricity for irrigation and other rural applications through development of low cost, small scale external combustion engines based on the Stirling cycle.
- In the poorest of the LDC's the problem of cooking is of paramount importance.
- The low efficiency of cooking stoves used by some 2 billion people in rural areas of LDC's is one

> of the outstanding energy problems of the world. Introduction of more efficient stoves coupled with efforts to establish woodlots could both stem the trend toward deforestation and improve the quality of life in rural areas of LDC's by making time available for activities other than gathering wood.

More than half of the energy consumed by people in many LDC's goes into cooking. This applies to rural areas and some slum areas around large cities, as can be seeen in Table 18, which compares primary energy consumption in the US and India.

As can be seen in this table the rural population of India spends 63% of their total energy expenditures in this particular activity.

Traditionally cooking is done in primitive stoves using wood as the main fuel. This has had serious consequences in devastating forests and in some sub-Sahara African countries long trips (~ 50 kilometers) have to be taken by families to gather wood for domestic use. It is estimated that 200-300 man-day of work are spent per family in India in the process of collecting wood[39]. Sometimes children are engaged in this work, diverting them from educational activities.

Manure (and crop residues) are sometimes used for cooking, thus consuming one of the important land fertilizers available in poor areas.

The efficiency of existing primitive stoves is low. Figure 15 shows schematically a typical rural stove.

Table 18. Primary Energy Consumption in the United States and India

Activity	United States(%)	India (%)
Transportation	25	3.5
Miscellaneous electric	19.5	4.5(lighting)
Feedstock and agriculture	7	22
Water heating	4	-
Space conditioning	19	-
Industrial processes	24	7
COOKING and clothes drying	1.5	63 (cooking)
Total	100.0	100.0

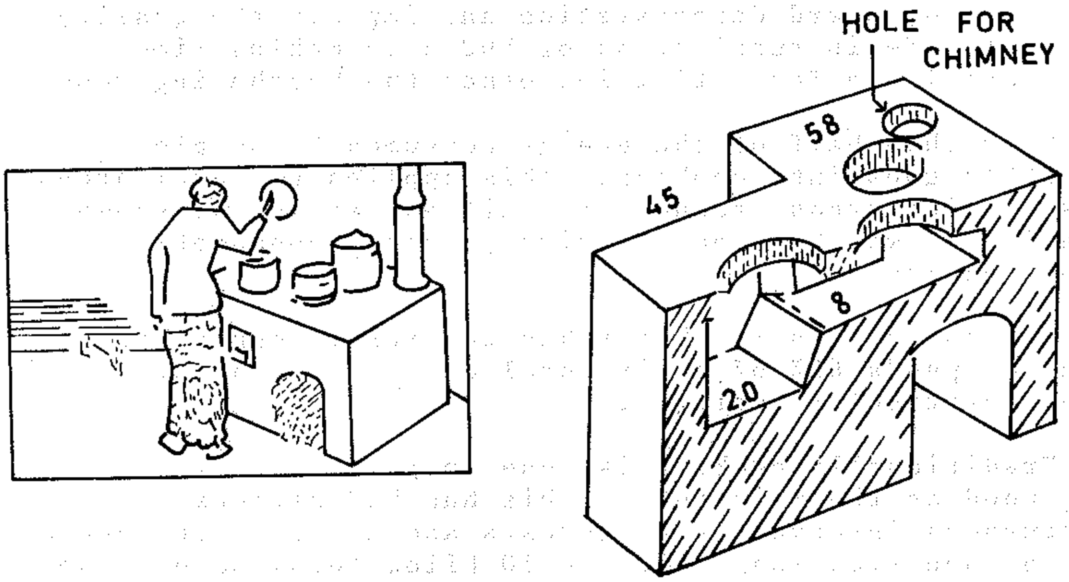

Fig. 15 - Rural Stove

Primitive wood cooking stoves generally have poor performance. One typical problem is lack of control of the air supply to meet combustion needs; another is that the air to fuel ratio cannot be maintained at a constant level everywhere in the burning mass. For example,if air enters at the bottom of the burning mass then the air/fuel ratio decreases as the air moves up and may fall in some places below the level needed to ensure combustion. In this case carbon monoxide is produced; a visual indicator of incomplete combustion is the emission of black smoke made up of fine carbon particles.

The result is that in most stoves used in rural areas one finds a smoky low temperature flame which is both inefficient and unhealthy. The fuel varies in its combustion properties from day to day and even in the course of a day because the humidity content in the fuel can change from batch to batch.

This description of the characteristics of primitive wood cooking stoves indicates clearly why people (even in rural areas) move to the use of bottled gas or kerosene as soon as they can afford it: combustion of these fuels is easy to turn on and off; it is simple to control the intensity of the flame and the fuel burns uniformly.

Typical efficiencies of wood stoves[40] are given in Table 19; in practice they do not exceed 10%.

The overall efficiency of modern gas ranges is 15%; of the total energy input in a typical unit (2.5×10^6 kcal/year) 41% is spent on the pilot lamps, 30% on miscellaneous losses and the remaining is used effectively in cooking; the surface burners are 48% efficient[41].

The overall efficiency of electric ranges is much higher (59%) so the total energy input is accordingly smaller (0.6×10^6 kcal/year at the input to the stove or 2×10^6 kcal of primary energy at the power plant); the reason is that the losses are smaller (21%) and more significantly the surface heaters are 74% efficient due to the close proximity of heater elements and the cooking parts, as can be seen in Table 20.

The need for advanced research, in a problem that looks so pedestrian as a cooking stove, is clear. This is an area where developed countries might contribute to the needed research efforts. Research is needed not only on hardware but on cultural factors as well. Otherwise people would not accept better designs of stoves as it happened when solar cookers were introduced in India.

Table 19. Wood Fire Efficiencies

Type of fire	Efficiency
Open fire	5 - 10%
Closed fire (one cooking hole, no chimney)	10 - 20%
Closed fire (two or more cooking holes, chimney draft control)	25 - 38%

Table 20. Comparison of Cooking Methods

	US 1976 Gas range	Electric range	Rural (Wood)
Primary energy input	6,900 kcal/day	1,810-5,700 kcal/day*	20,000 kcal/day
Overall efficiency	15%	18 - 59%	5%
Efficiency of surface burners	48%	73%	-
Reason for low efficiency	Pilot lights	-	Small solid angle
Approximate price of stove	US $294	US $344	Less than US $10**

*Depends on whether primary input is thermal or hydropower. Efficiency of thermal plants was taken as 30%. If transmission losses are also included the actual range is about 16-47%.

**US $10 was taken as the maximum cost of a rural wood cooking stove; in general no money is involved in the construction of such stoves and this is a very rough estimate.

V. ENERGY IMPLICATIONS OF SOCIAL CHANGE

It is not obvious that rural life is less energy intensive than urban life. The fact that a villager in India consumes 7,100 kcal/day while an average american consumes 243,000 kcal/day merely illustrates the fact that most villagers lead a miserable life consuming little more energy that is needed to stay alive.

Anyone familiar with rural areas in less developed countries (where approximately half of manking lives) knows that life in these areas is generally speaking very difficult, unhealthy and full of hard work and drudgery; health and sanitation problems, malnutrition, lack of education and outright poverty are the rule and not the exception in most of this part of the Third World.

The correct question to ask is "what is the energy consumption for urban and rural life for comparable levels of comfort in the same country?"

The answer to this question exists for the United States[42] and Norway[43] where the total energy consumed was calculated as a function of income for rural and urban households (Figure 16); direct and indirect energy expenses were taken into account.

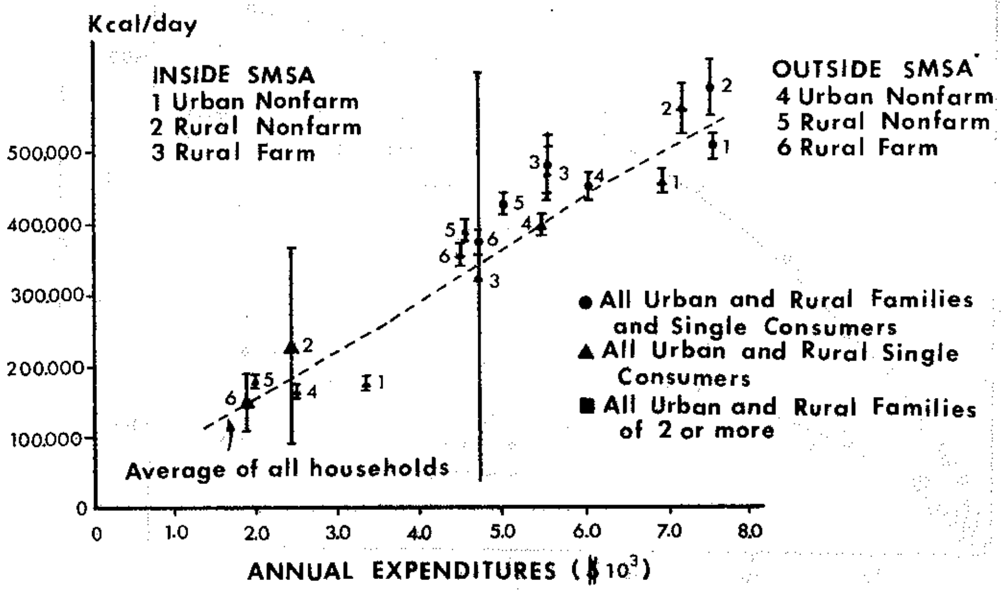

Fig. 16

In both these developed countries there is hardly any difference between the two categories with some indication that rural households are actually more energy intensive than urban. The main reason for that is the larger use of transportation in rural areas and the higher requirements for heating in the winter in isolated, badly thermally insulated farmhouses.

A similar study exists for Brazil, a large less developed country, using results of a household expenses survey conducted in 1974 by the Brazilian Statistics Bureau[44].

Results are shown in Figure 17 for the direct and total energy expenses for rural, urban non-metropolitan (small and medium size cities) and metropolitan areas, in the State of São Paulo one of the most populous states of Brazil.

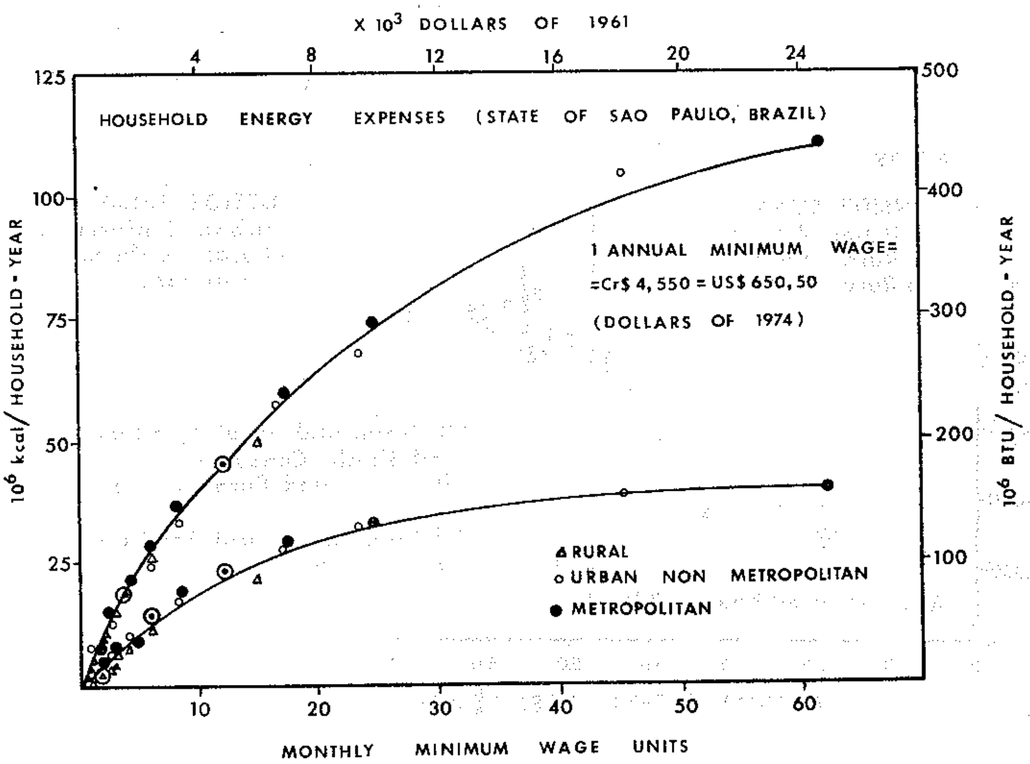

Fig. 17

As one can see, there is hardly any difference in the total energy expense of households for the <u>same income</u> (monetary and non-monetary incomes were added since the latter are very significant in rural areas).

This is in our view a very important and rather surprising result. Although presently there are few rural households with large incomes it seems inescapable that as their income increases they will fall in the general pattern of consumption in urban areas.

It could be argued that the quality of life in rural or urban non-metropolitan areas is better than life in metropolitan areas <u>for the same income</u>. This is probably true but involves a subjective scale of values. In any case it seems very unlikely that somewhat comparable levels of comfort could be obtained in rural and non-metropolitan areas with less than half the energy needed in metropolitan areas.

As a consequence if one really wants to improve the living conditions of the poor in most LDC's one should be prepared to expect very high requirements of energy.

The income distribution in LDC's as one well knows is rather unfair with most of the income concentrated in the hands of 10-20% of the population. This can be seen clearly in Figure 18 which shows the income distribution of the population of São Paulo whose energy expenses were analyzed and plotted in Figure 17.

It is obvious that presently, rural and urban non-metropolitan areas have more poor people than metropolitan areas and consequently they consume less energy.

If one multiplies the distribution of population as a function of income as given in Figure 18 by the energy consumption as a function of income one obtains the total energy consumption as a function of income. This is given in Figure 19. The area under this curve is the total energy consumed by the population (approximately 120×10^{15} cal).

It is interesting to notice that if a very severe redistribution of income were to take place, as indicated by the dotted line in Figure 18, (such uniform distribution was not even achieved in the US*) the energy consumption of the population would be distributed by the dotted line of Figure 19 which corresponds to a total energy consumption of 153×10^{15} cal. What this indicates is that the total energy requirements of society would not be very different form present ones. Redistribution of income would not lead to an inordinate increase in energy consumption.

This is another way of saying that there is enough energy being consumed nowadays in the world (and inside most countries) but that it is very unevenly distributed as can be seen in Table 21.

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*Distribution of income in the US (dollars of 1972)

	Average income	
Poor	- US$ 2.500	(18%)
between poverty level and US $11.199 - Lower Middle	- US$ 8.000	(42%)
between US $12.000 and 15.999 - Upper Middle	- US$ 14.000	(19%)
above US $16.000 - Well off	- US$ 24.500	(20%)
Medium income	- US$ 11.116	

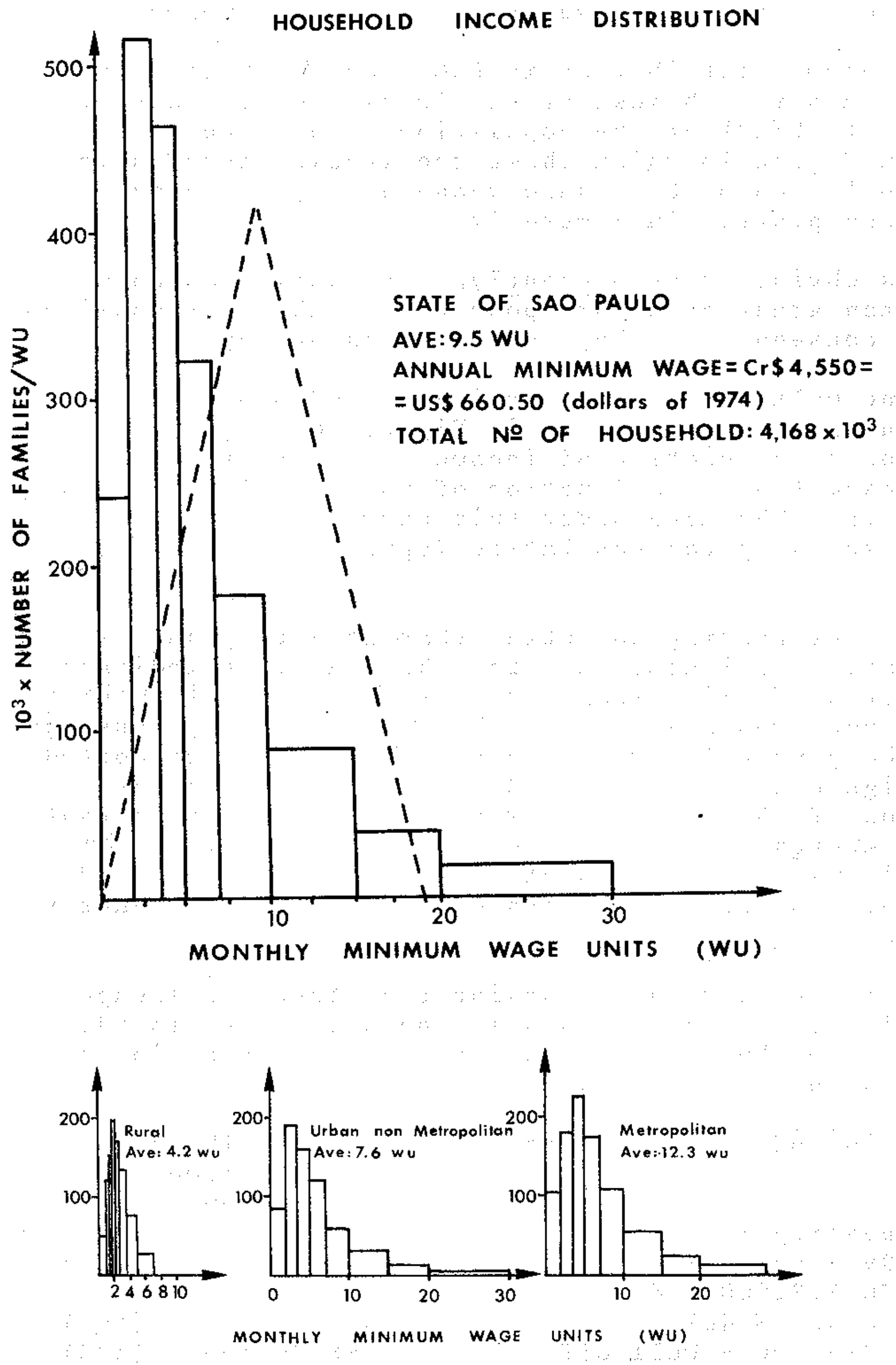
HOUSEHOLD INCOME DISTRIBUTION
STATE OF SAO PAULO
AVE: 9.5 WU
ANNUAL MINIMUM WAGE = Cr$ 4,550 =
= US$ 660.50 (dollars of 1974)
TOTAL Nº OF HOUSEHOLD: 4,168 x 10³
10³ x NUMBER OF FAMILIES/WU
500
400
300
200
100
10
20
30
MONTHLY MINIMUM WAGE UNITS (WU)
200
100
Rural
Ave: 4.2 wu
2 4 6 8 10
200
100
Urban non Metropolitan
Ave: 7.6 wu
0
10
20
30
200
100
Metropolitan
Ave: 12.3 wu
10
20
MONTHLY MINIMUM WAGE UNITS (WU)

Fig.18

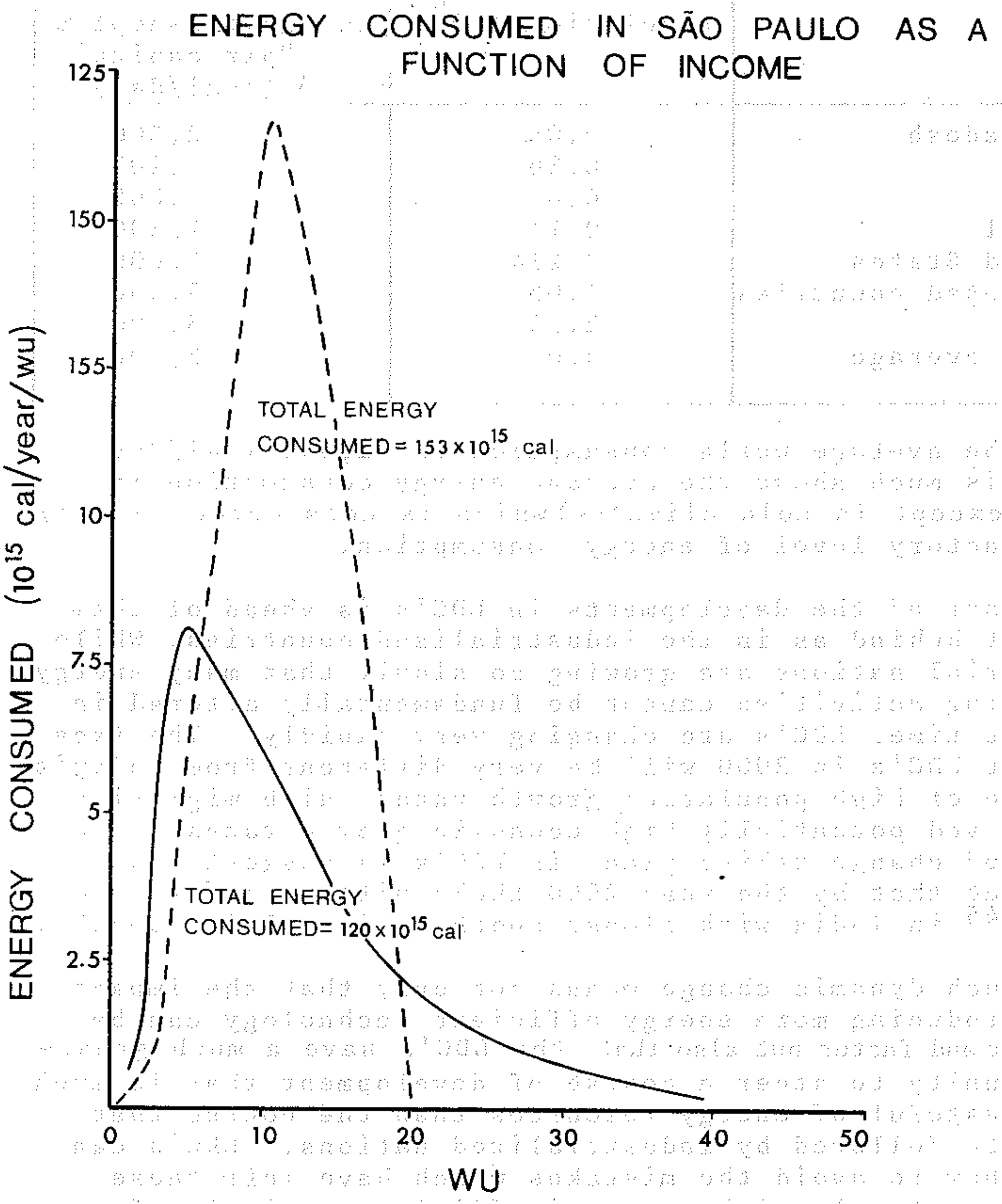
ENERGY CONSUMED IN SÃO PAULO AS A FUNCTION OF INCOME
ENERGY CONSUMED (10^15 cal/year/wu)
125
150
155
10
7.5
5
2.5
TOTAL ENERGY CONSUMED= 153x10^15 cal
TOTAL ENERGY CONSUMED= 120x10^15 cal
0
10
20
30
40
50
WU

Fig. 19

Table 21. Energy Consumption in Selected Countries

	Population (10^9)	Energy consumption "per capita" (kcal/day)
Bangladesh	0.08	2,300
China	0.88	7,100
India	0.6	11,000
Brazil	0.11	22,800
United States	0.214	243,000
Developed countries	1.05	110,000
LDC's	2.95	18,000
World average	4.0	42,500

The average world consumption is 42,500 kcal/day which is much above the average energy consumption in LDC's(except in cold climates)which is considered a very satisfactory level of energy consumption.

Most of the developments in LDC's is ahead of them and not behind as in the industrialized countries. While industrial nations are growing so slowly that many energy consuming activities cannot be fundamentally altered in a short time, LDC's are changing very rapidly. The face of most LDC's in 2000 will be very different from today's, because of high population growth rates, high migration rates, and potentially high economic growth rates. The scale of change taking place in LDC's is suggested by the fact that by the year 2000 there will be a " second India"[45] in India with almost another 600 million people.

Such dynamic change means not only that the impact of introducing more energy efficient technology can be greater and faster but also that the LDC's have a much greater opportunity to steer a course of development that is much less wasteful of energy resources than the course that has been followed by industrialized nations. LDC's can learn how to avoid the mistakes which have left these nations not only with energy inefficient capital infrastructures, but also with the adverse side effects of energy wasting technologies, such as polluted air and congested urban environments. Among the possibilities for alternative development are a revitalization of the railroads as an alternative to roads for freight transport and urban redesign to minimize the need for transportation. (Table 22)

Table 22. Transportation Modes in Brazil*

	kilojoule/ton-km
Trunk	2,340
Rail	420
Water	230
Air	83,200
Average	1,840

*The same average for the US (1972) is 890 showing how inefficient freight transportation is in Brazil.

Public policy initiatives to influence the course of development along such lines could lead to a saturation of consumer demands at levels far below those in industrialized nations. Through better urban design, for example, the "need" for the automobile could "saturate" in LDC's at a relatively low level, while living standards are improved by bringing living, working, marketing, and community service places closer together and by reducing the environmental degradation of cities.

The energy crisis should be a cause for hope rather than despair for fossil fuel poor LDC's. The new awareness of energy problems which resulted from the sharp increase in the world price of oil has focussed attention on the urgency of shifting away from petroleum based development strategies and has generated a creative ferment in the exploration of alternatives. Just as the " wood crisis" in 16th century Britain forced a shift to coal and set into motion a chain of events that culminated two centuries later in the Industrial Revolution[46], the present "petroleum crisis" could provide the impetus needed to shift LDC's to a course of sustainable development.

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