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MANUSCRIPT REPORTS

Renewable Energy Resources

Yves Lambert;
Djibril Fall;
José Fernando Isaza

July 1984

The Energy Research Group consists of eminent members of the international community of energy analysts and policymakers from developing countries. This independent Group has been set up to review energy-related research and technology and its relevance to developing countries, to assess the research capacity of developing countries, and to suggest the priorities for energy research in these countries.

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INTRODUCTION

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The papers in this Manuscript Report diverge from the general pattern of papers presented at the Energy Research Priorities Seminar in Ottawa in August 1983. Although the other papers reviewed the state of research and sought to draw conclusions from it for future research, this set of papers reports fieldwork results. They are being circulated because each presents a special point of interest.

The paper by Professor Lutz Hoffmann (Hoffmann 1984) outlined an approach to energy demand studies that involved the disaggregation of energy consumption to specific uses and the comparison of various technologies that could serve each use. Mr Yves Lambert's paper is an application of this approach. It does not include the figures of consumption and costs that a Hoffmann-type study would require and to that extent it is difficult to test the validity of Lambert's conclusions. However, it is perhaps difficult to marshal such detailed data for West Africa. Read in conjunction with its background material (especially Commisariat à l'Énergie Solaire 1980; Agence Française pour la Maîtrise de l'Énergie 1982), Lambert's paper provides a good map of the possibilities in West Africa. Professor Djibril Fall concentrates on some of the options, and reports on the work in progress in Senegal.

Mr José Fernando Isaza reports on the solar water heaters installed in Colombia. He stresses the extent of adaptive research and development (R&D) required, most of which was in system components other than the solar collectors. His paper perhaps carries a warning about over-specialization in energy research. Energy is an intermediate input, and improved energy technology will generally have to be fitted into products and equipment; some of it might, therefore, have better chances of success if it were undertaken by producers or institutions that do not narrowly specialize in energy.

References

Agence Française pour la Maîtrise de l'Énergie. 1982. Énergies renouvelables au Sahel: Evaluation des projets. Ministère de la Cooperation et du Developpement, Paris, France.

Commissariat à l'Énergie Solaire. 1980. Evaluation des énergies renouvelables pour les pays en développement (2eme éd.). Société de Conseil, d'Études et d'Ingeniére, Paris, France.

Hoffmann, L. 1984. Energy demand in developing countries: identification of research areas. In Energy demand patterns. Energy Research Group, Ottawa, Canada. ERG-MR2e, p. 5-14.

ENERGY NEEDS IN WEST AFRICAN COUNTRIES: POSSIBLE CONTRIBUTION OF RENEWABLE ENERGY

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with the collaboration of
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Among the various obstacles to development in developing countries, food and energy are generally put first. When it comes to those nonoil-producing Sahelian countries where desertification and lack of firewood constitute a permanent threat to the people, what are their energy needs in the medium and short term? To what extent does "renewable energy" as it is called, contribute to their fulfillment?

Energy Resources

West African countries frequently face a dilemma:

- Increasingly heavy oil costs and lack of substitutes for oil where the transport industry is a large consumer; and
- A dearth of conventional fuels and in particular firewood, which accounts for 60-90% of all consumed energy.

Energy consumption varies of course from one country to another, particularly in respect of conventional energies; it is, however, very low compared to industrialized countries.

Commercialized energy

Commercialized energy consumption, in terms of kilogram equivalents of oil per person, was in 1979; Upper Volta, 20 kg; Niger, 32 kg; Mauritania, 120 kg (for lack of noncommercialized wood); Senegal, 180 kg; and Ivory Coast, 280 kg. For comparison, consumption in France was 3330 kg and in the USA, 8230 kg.

This use of commercialized energy is in fact restricted to the urbanized sector of the population. Lamp oil, sometimes used for lightning, is of interest mostly to the rural and suburban zones but, in West Africa, accounts for less than 5% of all oil products consumed. The other oil by-products would also fuel generators, pumps, and vehicles, but quantities used for these purposes remain marginal.

Electric power distribution networks are in operation, but they supply only the capitals and major cities. Even in Ivory Coast where a rural power-distribution program is being developed, only a minority of people will benefit from it. For the whole of West Africa, electric power consumption in rural areas may be described as virtually nonexistent.

Thus, a specific characteristic of the West African -- and particularly Sahelian -- countries is that their commercialized energy consumption is restricted to urbanized areas. Moreover, because the cost of importing oil to

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satisfy this need grows faster than the amount of exported goods, it follows that most of these countries suffer a growing deficit in their trade balance, largely for the benefit of the urban population.

Traditional energy

Traditional energy, i.e., that extracted from wood, charcoal, and vegetable waste (millet or sorghum stalks, peanut shells, etc.), constitutes the most important source of energy in the West African region of the Communauté économique de l'Afrique de l'Ouest (CEAO) and the Comité permanent interétats de lutte contre la sécheresse dans le Sahel (CILSS) (Fig. 1). More than 75% of all energy consumed in the region comes from wood, and this figure rises to around 90% in countries like Upper Volta, Mali, Niger, and Chad.

In rural areas, wood (and possibly vegetable waste) is the only source of energy, apart from human and animal energy. It is used for cooking meals and heating water, of course, but it is used also for heating the home during cold periods as well as for ironing clothes and for lighting. Burning wood is often the only source of light at night and at dawn.

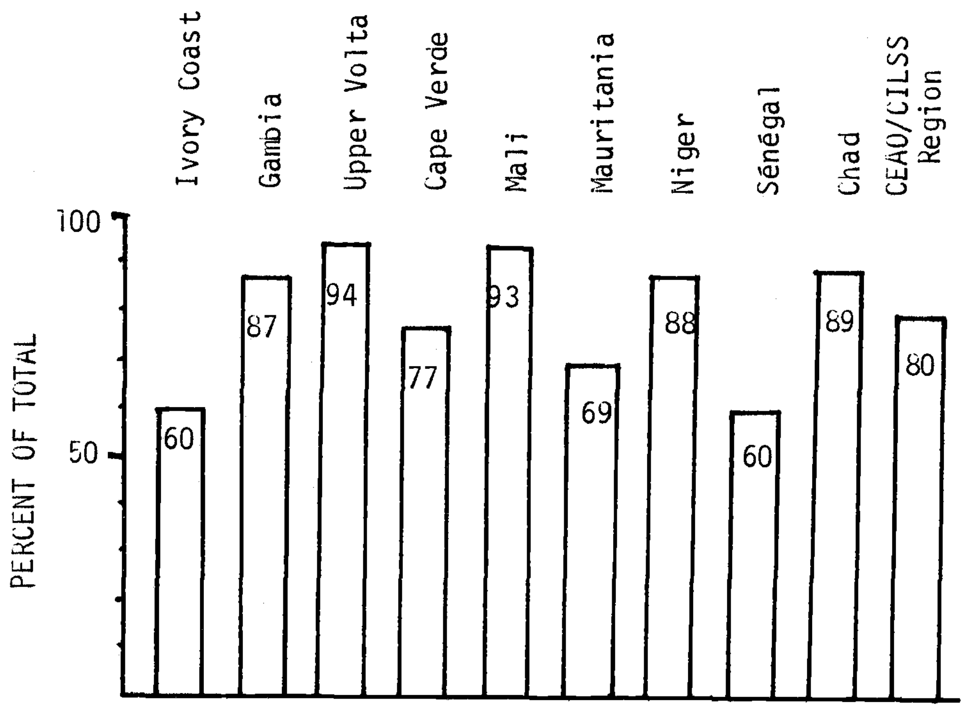

Fig. 1. Wood used in energy supply.

Wood is also important in supplying energy to urban and suburban zones, either as raw wood or as charcoal. The cost of cooking wood is high, however,and often accounts for one-third of individual incomes. Apart from domestic use, wood is an important item in some craftworks: for example, blacksmiths, pottery makers, brick makers, and fish drying and smoking.

Wood consumption in the Sahelian region is estimated at 500 kg/person per year. Unfortunately, population growth has resulted in a parallel growth of demand at a time when an increase in herd numbers, combined with a severe drought, has curbed production. Therefore, many problems of wood supply have appeared:

- Increase in distance required to collect wood: even in rural areas, some families would have to walk 5-10 km. Around capitals of the Sahelian zone, almost 100 km must be traveled before reaching a wood-collecting area;

- Wood prices rose quickly in the capital cities owing to its scarcity and transport costs and 25-40% of income may be used by low-income families to buy wood;

- Detrimental effect on soil fertility of increasing use of vegetable waste (such as millet or sorghum stalks); and

- Changes in the household regime, for example, daily consumption of hot meals has been reduced.

In many moderately or heavily populated zones, wood consumption has now gone beyond natural wood production so that people are actually consuming their forest capital. For the region as a whole, this situation is still under control -- but for how long?

Wood supplies, therefore, and particularly those for cooking or water heating, are diminishing, and it is a priority to look for some acceptable and viable solutions, both to increase production and to reduce consumption by increased efficiency (e.g., improved stoves) or by substituting new fuels for the present ones.

If none of this is done, deforestation will gain momentum and people without wood will only be able to use the "classical" energies (oil or gas), thus increasing the balance-of-trade deficit.

The present situation in the Sahelian countries is very worrying:

- The oil bill is becoming almost insupportable and is limiting consumption of oil products. This is acting as a brake on overall development;

- An important fraction of the population will still be deprived of electric power and, as a result, of electrical lighting, which may be considered as a priority need;

- Deforestation will increase and overtake the whole Sahelian region; and

- There will be an increase in rural depopulation.

Energy-Fueled Needs to be Met

Relationships between energy and the basic needs may be outlined schematically (Fig. 2) and their relative weights estimated (Fig. 3). Equally, priorities for these needs can be set (Table 1).

To define those energy needs corresponding to these basic needs, we must identify different energy types:

- Thermal energy - heat for cooking, drying, and crafts;
- Mechanical - human, animal, and motorized energy; and
- Electrical.

Equally, we must define availability, their energy characteristics, and marketing.

Food

Several aspects of the relationship of energy to food should be studied. However, they can be grouped into agriculture and husbandry (Table 2) and cooking (Table 3).

Agriculture

Activities such as tilling, sowing, weeding, irrigating, harvesting, processing and preserving of products all require some mechanical or thermal energy. This may be animal energy (e.g., tilling with horses or oxen, or powering water pumps) or mechanized energy (e.g., tractors or motors). It should be remembered that fertilizers contain energy. Analysis has shown the need for reasoning in terms of energy rather than power and not to overlook the time factor when greater power is available than that needed in sowing or weeding, for example - such power can be used for a relatively long period (e.g., tilling) whereas weeding must be performed at a very specific time and needs much labour for a few days, thus warranting priority for mechanized weeding.

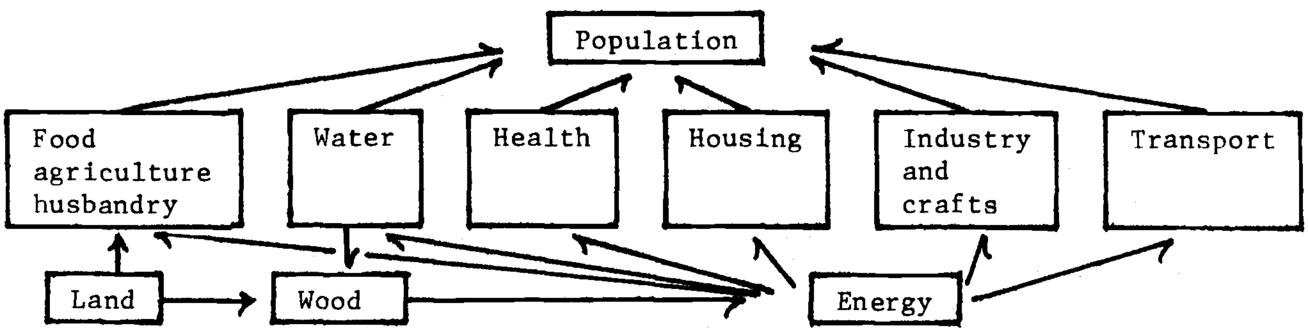

Fig. 2. Relations between energy and basic population needs.

Table 1. Priorities for main energy needs in the region

To maintain the ecological balance of the region	To meet people's essential needs	To alleviate the oil bill burdern
*** Cooking, hot water, rural heating	*** Drinking water	*** Transport
	*** Irrigation	*** Industry
** Fodder preservation	** Food preservation	** Residential and tertiary services
	** Lighting	
** Agricultural soil improvement	** Other (health, education, and communication)	
* Needs of artisanal and small industries	* Crop preservation	
	* Motorization of agriculture	

*** Very important   ** Important   * Average

For the sake of comprehensiveness, we should include consumption of energy by the farmers traveling to the fields, which are sometimes several kilometres from their homes.

Finally, from being consumers of energy, farmers could become suppliers of energy because agricultural wastes have a potential of being converted into energy. Then, it would not be unrealistic to imagine an integrated farm enjoying some form of "energy autonomy."

Husbandry

Searches for pasture, raising water, and travel to markets are energy (or calorie) consuming activities. Cattle traveling long distances lose weight and thus value. These losses may be substantial and should be quantified so that, from a macroeconomic viewpoint, development of watering points would be warranted. Finally, much as in agriculture, husbandry might supply some energy because animal manure would allow gas and fertilizer production.

Cooking

Water is often needed for cooking, but more important is the need for fuel. "What's the use of foodstuff, where there is no wood to cook it?" Warnings of this kind demonstrate the need to study the food problem as a whole and not only with regard to resources.

Because firewood is virtually the only source of fuel used in rural areas, the cooking problem has produced a host of proposals, particularly for using solar energy. This explains why many people see a solar-energy stove as the answer to the desertification problem. This example, however, should be analyzed, because it is underpinned by faulty reasoning. The mere existence of a technological solution does not imply its feasibility. Indeed, a reliable specification document shows that chances are minimal that solar-energy stoves would be usable in the Sahel:

- Cooking takes place most often in the early hours or at night, before and after a full day spent in the fields or at the market. In many countries, farmers take some food with them to the fields for the day. However, solar stoves can only be operated about 6 hours/day, between 9 a.m. and 3 p.m.;

- Kitchens are normally built in the shade, whereas solar stoves have to be exposed to the full sun;

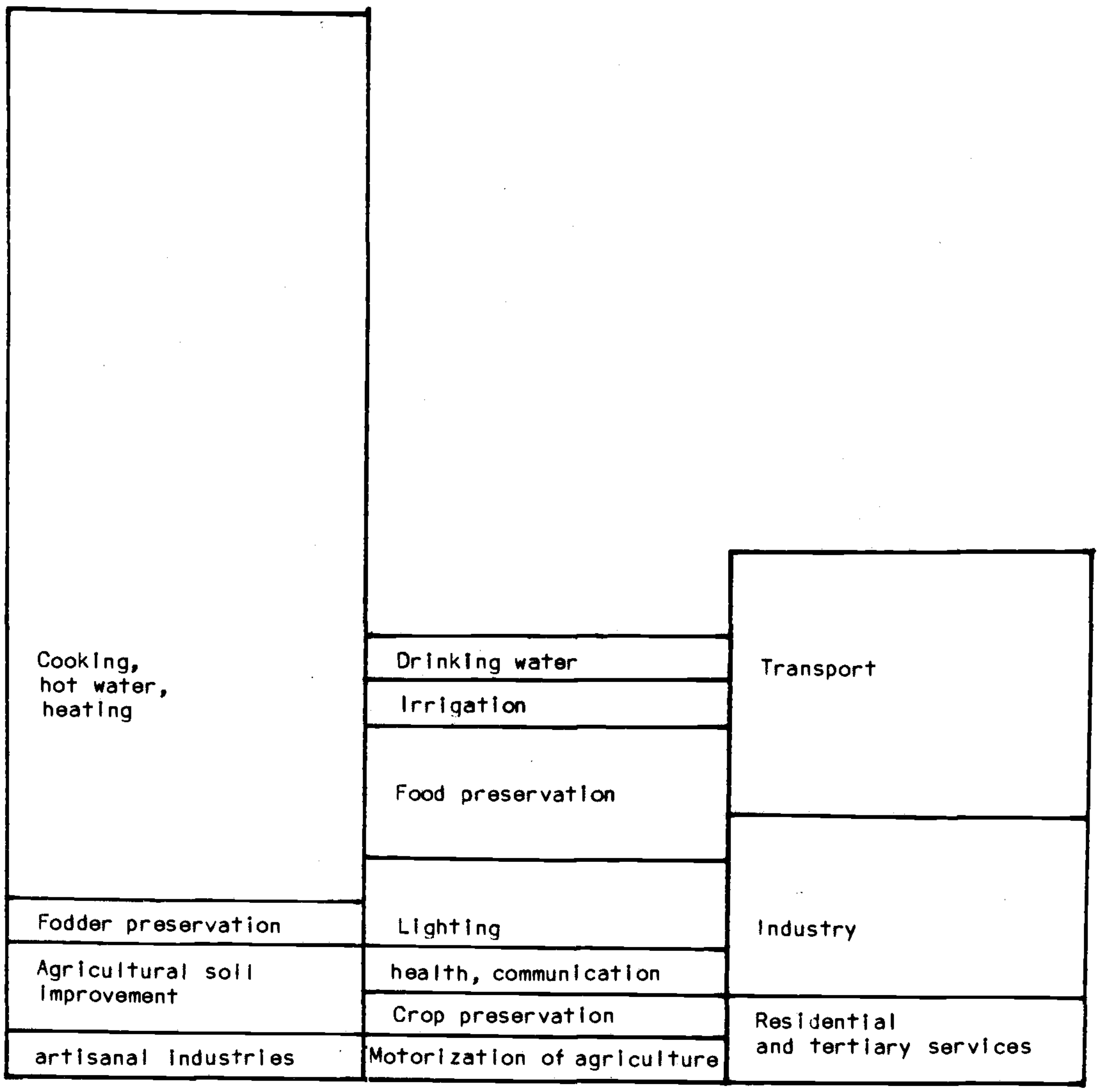

Fig. 3. Estimated relative weights of various energy needs.

Table 2. Energy needs related to agriculture and husbandry

	Agriculture				Husbandry	
	Land improvement	Irrigation	Motorization	Crop preservation	Water	Fodder
Traditional ways of meeting needs	Artificial fertilizers (50% of needs)	Surface water diversion and pumping	Very few motorized tasks	Drying in open	Surface water	Nil
Traditional resources used	--	Human and diesel power	Mostly human power	Sun and wind	Human and animal power	--
Bottlenecks due to traditional ways of meeting needs	Impoverishment of land, lower yields	Limited potential, dearth of foodstuffs due to drought	Limited productivity, arduous tasks	Loss of yield and quality, poor hygiene	Herds decimated due to drought	Overgrazing, livestock wasting away
Impact on:						
Energy imports	Average	Small	Small	Very small	Small	Very small
Rural development	Large	Very large	Average	Average	Large	Large
The environment	Large	Average	Average	Average	Average	Large
Energy-saving potential	Average	Very small	Small	Very small	Very small	Very small

Table 3. Energy needs for rural households

	Cooking, water, and home heating	Drinking water	Food preservation	Lighting	Other (health, education, and communication)
Traditional ways of meeting needs	Open fire and plain stove	Raising ground water from well	Drying in open	Open fire, traditional and storm-proof lamps	Miscellaneous
Traditional resources	Wood and charcoal	Human and diesel power	Sun and wind	Wood, vegetable waste, and lamp oil	Oil and electricity
Bottlenecks originating from traditional ways of meeting needs	Faulty fuel use and charcoal making resulting in dearth of firewood and in deforestation	Insufficient water supply and quality	Loss of performance, quality, and hygiene. Periodic risk of dearth	Impossible to develop an all-region network	Fuel price and transport means
Impact on:					
Energy imports	Very low	Low	Very low	Low	Low
Rural development	Large	Very large	Large	Large	Large
The environment	Very large	Average	Average	Low	Low
Energy-saving potential	Very large	Very low	Very low	Low	Low

- While cooking, women quite often carry an infant on their back. Because solar stoves must be adjusted periodically (every 5 minutes) to the sun's rays, this exposure to the sun would create a serious hazard to both mother and child under the tropical heat; and

- There is an increased risk of being burned, costs are and will remain relatively high, and solar-cooked food lacks flavour.

A careful preliminary study has shown that solar stoves are not the answer to the problem; besides the fact that it would be hardly conceivable to introduce such a fundamental change in rural people's habits. By contrast, a special solar stove with a plane collector and some storage capacity might be usable if costs could be made competitive. However, other solutions could be tried to resolve the cooking problem:

- People might be urged to plant trees to have a woodlot of their own, thus encouraging a replacement of a renewable resource that is on the verge of exhaustion;

- Traditional stoves should be improved for better performance;

- Better-designed cookers would allow food to be prepared faster; and

- Use of biogas should be promoted.

Water

We have stressed the importance of water in farming and cooking. The lowest figures estimate the minimum requirement as 10-20 L/person per day for drinking, cooking, laundering, etc. Energy is needed to raise water from a well shaft or a drilled well, and some energy (often more) is needed to carry it from the water hole to the home. In many countries, the main problem with water is one of multiplying the points of water availability, so that people would not have to walk several kilometres for that purpose. An added problem occurs when water must be desalinated.

Pumping

Wind or solar pumps or other alternatives to generators should be compared to manual pumps. However, it should be realized that they would hardly be acceptable for pastures or irrigation because the quantities of water needed are much larger than those of the villages.

The importance of quantity problems, however, should not divert our attention from those of water quality. It should be noted that water from a drilled well has a better safety factor than that from an open well, although the farmer needs some way of pumping (manual or motorized). However, pumped water could come brackish. Some people would not mind, but it is often necessary to go through the process of desalination.

Desalination

Desalination of water is crucial for people living in isolated villages of the hinterland or on islands where any available water is taken from the sea.

Energy consumption is then needed, either thermal energy for mechanical distillation or electrical energy where reverse osmosis or electrolysis is used. Sometimes it is also necessary for special uses other than cooking, e.g., to heat the water or to have it sterilized as is the case in clinics and hospitals. Here thermal or electrical energies are necessary and some renewable energies could also be considered.

Health

Several health aspects related to water, i.e., hygiene, heating, and sterilization that may in different ways influence people's health, have already been discussed, but, from an energy point of view, health needs will differ if preventive or curative medicine is considered. Preventive medicine would necessitate the presence of mobile teams and means of transport and equipment with its own built-in energy source. Curative medicine would require more centralized and versatile energy for use in clinics and hospitals.

Without going into much detail, apart from needs directly linked to water, the main energy needs in this area would be related to vaccine and drug preservation, lighting, ventilation, the operation of some surgical equipment, and perhaps a radio-telephone set.

Housing

Rural populations today claim their right to some kind of comfort and copy urban-housing models, sometimes with unhappy results. A house with filled stone walls and a corrugated iron roof is impractical in the heat of the afternoon and becomes a resonance box on a rainy day. Traditional solutions were wiser, because they were based on the accumulated thinking, knowledge, and experimenting of successive generations. "Bioclimatic architecture" existed and was practiced long before it was given a name and became a fashionable concept.

Designing houses with regard to climatic conditions might be the way to improve interior comfort without resorting to power consumption as is the case in air-conditioned dwellings.

Construction materials

Construction work should use local materials, whether manufactured or not. Bricks or tiles are produced in many countries, but the process involved should be analyzed for energy consumption because of the amount of wood required. Is it really necessary to heat up to 700-800°C in the brick-making industry? Could some other insulating material be produced for roofing? Should we not try to reintroduce lime, because it is known as an excellent binding agent? Considering energy needs of house construction means that materials should be selected according to their local availability as well as their insulation capacity, permeability, etc.

Electrification

Improvements in the area of lighting, ventilation, refrigeration, and other household appliances may help satisfy farmers' yearnings for "comfort" and, therefore, reduce rural depopulation. Rural electrification, however, is dragging on and it is expensive in its form of centralized network. Apart from distribution costs of 100,000-150,000 francs/km for wiring, equipment maintenance and costs to the consumer restrain rural grid development. With "renewable energies" and particularly solar energy with its photovoltaic component, one may wonder if power networks should come as they are already planned or, rather, if electrification concepts should be given a second thought, in the line of producing new equipment with built-in energy power. Every family and every household would be able to purchase their preferred items without having to be linked to a power-distribution network.

For mechanical needs such as millet-pounding equipment, sewing machines, etc., wind mill or solar energy could be substituted for the most common energy used at this time, i.e., human work. The various needs related to cooking and water use have already been analyzed above.

Crafts and Industry

Blacksmiths, carpenters, and jewellers all need some kind of thermal and mechanical energy (Table 4). Here again renewable energy solutions might be considered, but needs, temperatures, power, and operating periods should be covered by preliminary studies.

Usually, agricultural products are processed in large cities because the required energy is often not available in rural areas. By using agricultural waste and solar energy (for drying purposes for example), it would be possible to generate in the rural areas whatever energy would be needed for processing and preserving agricultural products. Increased local added value (and, as a consequence, increased income) might then help close the gap between rural and urban incomes and curb rural depopulation.

Communications

Better means of transport may also promote rural development by improving supply of manufactured goods to rural populations and helping them dispose of their produce and cattle. Transport, however, is a heavy energy consumer. Donkey-drawn carts in Upper Volta no longer suffice to supply wood to the residents of the capital city of Ouagadougou or to carry water cans from one place to another.

In the absence of new solutions to be implemented, it may become necessary to resort to other means that, unfortunately, may increase the foreign currency deficit resulting from oil bill payments.

Radio, telephone, or telex connections may alleviate the feeling of isolation in some villages or regions. Necessary energy to operate this equipment (radio-relays, radio-transmitters and receptors) may remain quite low but sufficient reliability could be achieved by the simple use of photovoltaic cells.

Television could play an educational role and help distribute information regarding food and health problems. Less than 20 W are needed to operate a television set for collective reception.

For all equipment existing in rural areas, efforts directed toward energy saving should be carried on. Provision of services could quite often coexist with reduced energy consumption. Development does not always depend on increased energy consumption.

Energy needs in rural areas - Summary

- Thermal energy: cooking, water heating, heating of the home, crop drying, lighting (special case), cooling systems, air conditioning, and refrigeration;

Table 4. Some examples of energy needs of artisanal and small industry

	Karite-nut butter manufacture	Brickmaking	Ironwork	Dehulling mills	Mechanics workshops
Estimated scale of business	Low 10 t/year	Low 50 t/year	Average	Craft scale 2.4 t/year	Low
Specific energy needs	2 kW.h/kg	700 kW.h/day	40 kW.h/day	4 kW.h/day	10 kW.h/day
Type of energy need	Heat	Heat	Heat	Mechanical Heat	Mechanical
Bottlenecks orginating from traditional ways of meeting needs	Wood depletion Desertification	Wood depletion Desertification	Wood depletion Desertification	Fuel costs Transport	Fuel costs Transport
Impact on:					
Energy imports	Very low	Very low	Very low	Low	Low
Rural development	Average	Average	Average	Average	Average
The environment	Average	Average	Average	Very low	Very low
Energy-saving potential	Average	Average	Average	Very low	Very low

- Mechanical energy: water pumping, farm work, transport of people and goods, home food preparation (such as cereal milling or pounding), and crafts;

- Electrical energy: lighting, small electric house equipment, crafts, etc.

The first attempt at surveying energy needs in rural areas showed how necessary it is to better identify needs in terms of quantities, quality, and time. For example, investigations into work periods would help understand distribution of needs within a day and a year (seasonability). The importance of firewood marketing is also poorly documented, as are the costs of moving the wood (time and energy required for gathering, etc.)

Such technical and economical comments should be followed by a social analysis of rural people's behaviour. It has been noted, for example, that many new technologies or changes in distribution of tasks have already been rejected.

To specify a product with the best chances of being accepted and integrated, it would require a good understanding of factors such as environment, technical skills (blacksmiths' in particular), traditions, etc.

Energy needs in the modern sector - Summary

Almost 50% of the energy needs of the modern sector are in transport (Table 5) where the resource required is primarily light petroleum products. None of the major uses of energy in the modern sector have much impact on the environment but their impact on the national oil bill is considerable.

Table 5. Energy needs in the modern sector

	Residential and services	Industry	Transport
Consumption (% of total)	14	38	48
Resources used	Electricity	Heavy oil products and electricity	Light oil products
Bottlenecks and problems of meeting needs	Unrationalized use and large oil bill	Unrationalized use and large oil bill	Unrationalized use and large oil bill
Impact on:			
Energy imports	High	Very high	Very high
Rural development	Very low	Very low	Average
The environment	Very low	Very low	Low
Energy-saving	potential	Average	High
High			

Effect of Renewable Energies on Rural Development

To analyze the role of renewable energies in rural development, it is essential to understand better those resources that are related to them and the development status of main conversion routes.

Resources

Solar radiation may be collected in two ways: naturally and artificially. Solar elevation is of great importance at the globe's surface. With a capture ratio of 10%, a few dozen square kilometres of collectors would supply enough energy for the needs of all Sahelian countries.

Natural collection

Hydraulic energy: This resource is very unevenly distributed over the globe surface. Data to be considered are: discharge rates, height of falls, and seasonal variations.

Wind energy: This resource prevails along coastal areas and on islands. It could be used in Sahelian countries above the 17th parallel. Because recoverable energy is proportional to the cube of the wind speed, it is necessary, when specifying equipment, to possess an accurate knowledge of all measurable wind speeds, not of an average speed.

Photosynthesis or green energy: Plants, seaweeds, and vegetation in general accumulate solar energy. Photosynthetic processes convert light energy into chemical energy, with an effective conversion ratio of 0.5-2% year-round. Agriculture by-products (such as millet or rice straw, peanut shells, etc.) and forest biomass represent amounts of dry materials that may vary considerably from one region to another.

Temperature gradient of the seas: Warming of the surface waters allows energy recovery in line with Carnot's principle (bottom waters being the cold source). The potential is great, but conversion techniques are still experimental.

Artificial collection

Solar energy that can be collected by plane or concentration collectors or by photovoltaic cells is in the range of 5-6 kW.h/m^2 per day in tropical countries. Measurements have helped distinguish between global radiation and normal direct radiation (the only one to be considered with regard to concentration collectors). Distribution of frequencies over time is also required to correctly size storage facilities.

Technological routes for conversion

Where renewable energies are expected to be the answer to specific needs, several technological routes may be considered (Fig. 4). Selection of a route should be determined by its adaptability to local resources and needs, its cost, reliability, etc. Given the highly diversified conditions prevailing in developing countries, it is quite improbable that a single route would be suitable. However, some routes seem today more promising than others.

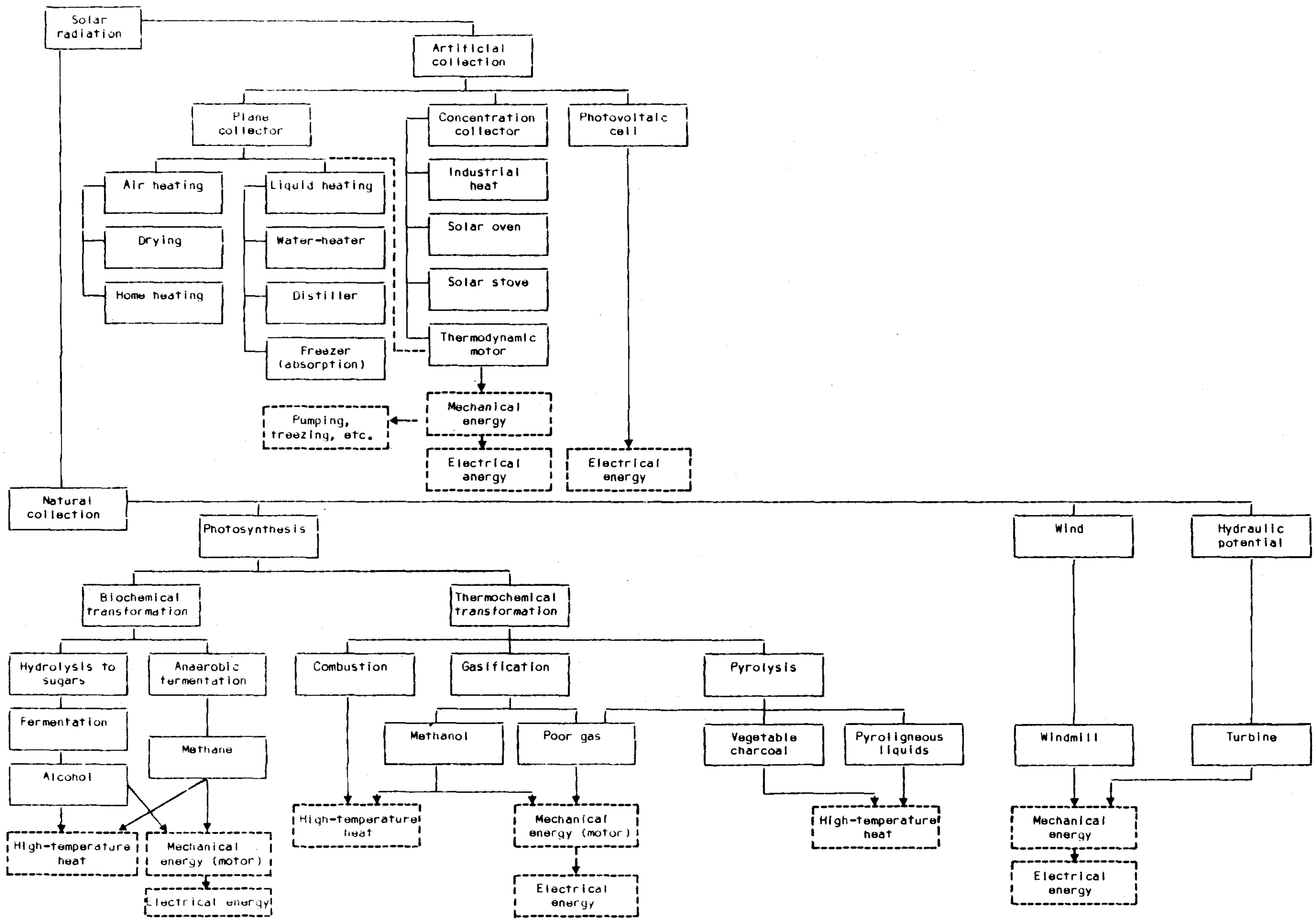

Fig. 4. Main transformation routes for solar radiation.

- Plane solar collectors may be manufactured locally and used for multiple purposes: drying, water heating, distillation, heat for mechanical energy, or for freezing. They are generally good for meeting thermal needs.

- Concentration solar collectors probably have prospects in the more distant future for high-temperature heat production.

- Photovoltaic generators are, at present, restricted to supplying power to very small, isolated plants. However, their scope of application should develop in line with the expected decline in cell costs. Possible uses would be for: telecommunications; signalling; water pumping; small-scale village power distribution; etc.

- Vegetable waste could be used through gasification, biogas, and ethanol or methanol production. Some techniques are already quite competitive with oil products in supplying mechanical or electrical energy under specific conditions, notably with gasification of certain wastes where the gas produced can supply mixed diesel engines. Methanol and ethanol routes of conversion should soon become competitive also.

- Small-scale hydrolectric plants are technologically very reliable, they offer a quite interesting solution for power supply to small communities located near a suitable watercourse.

- Windmills are a solution in windswept areas for all sorts of uses, including water pumping. In regions that are both isolated and wind-swept, they are also competitive for electric-power production (wind generators).

Contribution of renewable energies to development

Several renewable energies are technically operational and economically competitive wherever the site to be supplied is remotely located (far from a city, a transport route, on an island, etc.). Because renewable energies are scattered and decentralized, many uses can be contemplated.

Possible solutions to expressed needs are described in the appendix (Tables 8, 9, and 10).

Experience in West Africa

Since 1960, considerable research has been done in the various Sahelian countries, particularly in Senegal, Niger, and Upper Volta, and many projects are now under way (Table 6).

Since 1980, the countries of CEAO and CILSS have agreed to pool their results and to cooperate in the Centre regional d'énergie solaire (CRES), which is being built at Bamako in Mali.

The first studies have allowed research priorities to be defined for each country (Table 7) but it must be remembered that resources differ from one country to another and even within the countries themselves (Fig. 5).

The next stages of regional cooperation in West Africa are thus:

- Better sharing of activities (research, information, etc.);

- Organization of research at all levels; and

- Establishment of structures for manufacture, distribution, and maintenance of equipment that exploits renewable energy.

Table 6. Some achievements in the region

Technology and uses	Location	Nominal characteristics	Use	Date of bringing into service
Solar thermal				
Collective solar water-heater	Palm Beach Hotel, Sali Portudal, Senegal	500 m^2 of plane collectors; 40000 L/day	Hot water; sanitary equipment	1981
Solar thermodynamic				
Pumping and electricity production	Dire, Mali	3500 m^2 of plane collectors; 2 x 25 kW pumping 1 x 20 kW electricity production	Irrigation 100 ha (8400 m^3/day); lighting; cold storage	1979
Electricity production	Diakhao, Senegal	2000 m^2 of plane collectors; 25 kW, 220 kW.h/day	Power plant (2000 population)	1981
Solar photovoltaic				
Pumping	Ong Caritas, M'bour region, Senegal	4 pumps 2600 W; 2 pumps 1800 W	Hydraulics at the village level and irrigation (Pump 2600 W -- 125 m^3/day for 500 inhabitants and 3 ha of cultivated land)	3 pumps operating in 1980, 3 others planned for 1981
Electricity production	San Hospital, Mali	8.5 kW (peak) electricity production; 1 kW (peak) pumping; 25 kW.h/day; 26 m^3/day at 30 m depth	100-bed hospital: Surgical unit, lighting, ventilation, and drinking water	1979

Table 6 concluded.

Technology and uses	Location	Nominal characteristics	Use	Date of bringing into service
Windmill				
Pumping	Four villages on "Great Coast", Senegal	Savonius windmill and Vergnet pump	Hydraulics at the village level	1978-79
	San Nicolau, Cape Verde Islands	Aerogenerator (output of 4.5 m^3/h at 7 m/sec)	Irrigation of 4 ha	1980
Biomass				
Biogas production	Agronomic station, Saria, Upper Volta	4 digesters (4 tanks, each 4 m^3) with 1 metallic gasometer (3.5 m^3) and 1 soft tarpaulin gasometer (5 m^3) producing 4 m^3/day of biogas	Cooking, lighting, and fueling a pump motor for irrigation	1980
Firewood				
Improved fireplaces	Centre d'études et de recherches sur les énergies renouvelables, Senegal	Wood saving, 30-50% each household	Firewood savings for Sahelian households	Launching of program March 1980 2000 achieved, 802 of them in rural areas

Table 7. Principle active research topics in the CEAO/CILSS countries

Cape Verde	Multiblade windmills
Senegal	Solar thermal and thermodynamic Savonius windmills Biogas Gasification Improved stoves Solar photovoltaic
Mali	Solar thermal Improved stoves Biogas
Ivory Coast	Biogas Gasification
Upper Volta	Solar thermal Savonius windmills
Niger	Solar thermal and thermodynamic Biogas Improved stoves

Conclusion

For renewable energies to be used extensively in the development field, many technological improvements will have to take place. Even when this is done, new technologies cannot be expected to be adopted immediately. Advancement will be slow and related to evidence of achievement. Needs identification and potential users' solvency would not suffice to guarantee a reliable market, particularly for innovations in a rural setting. Peasants are basically suspicious and some time would elapse before they could be convinced to modify their routine.

Considering the present low energy consumption in rural areas (with the exception of firewood), it should not be substitution of the "classical" energies that should be researched, but rather supply of services that, up to now, were not available to those people.

The dispersion of solar energy then becomes an advantage, for it allows the use of decentralized equipment whether over wide-spread areas or on archipelagos. Also, local processing of agricultural products, for example, might allow a greater local added value to the goods, and, as a consequence, improve rural people's income. Finally, some kind of "comfort" would come as a bonus, e.g., lighting, refrigerators, fans, radios, all appliances that could be operated from photocells or wind-generators.

These different factors would allow a new type of rural development and, as a consequence, reduce rural depopulation.

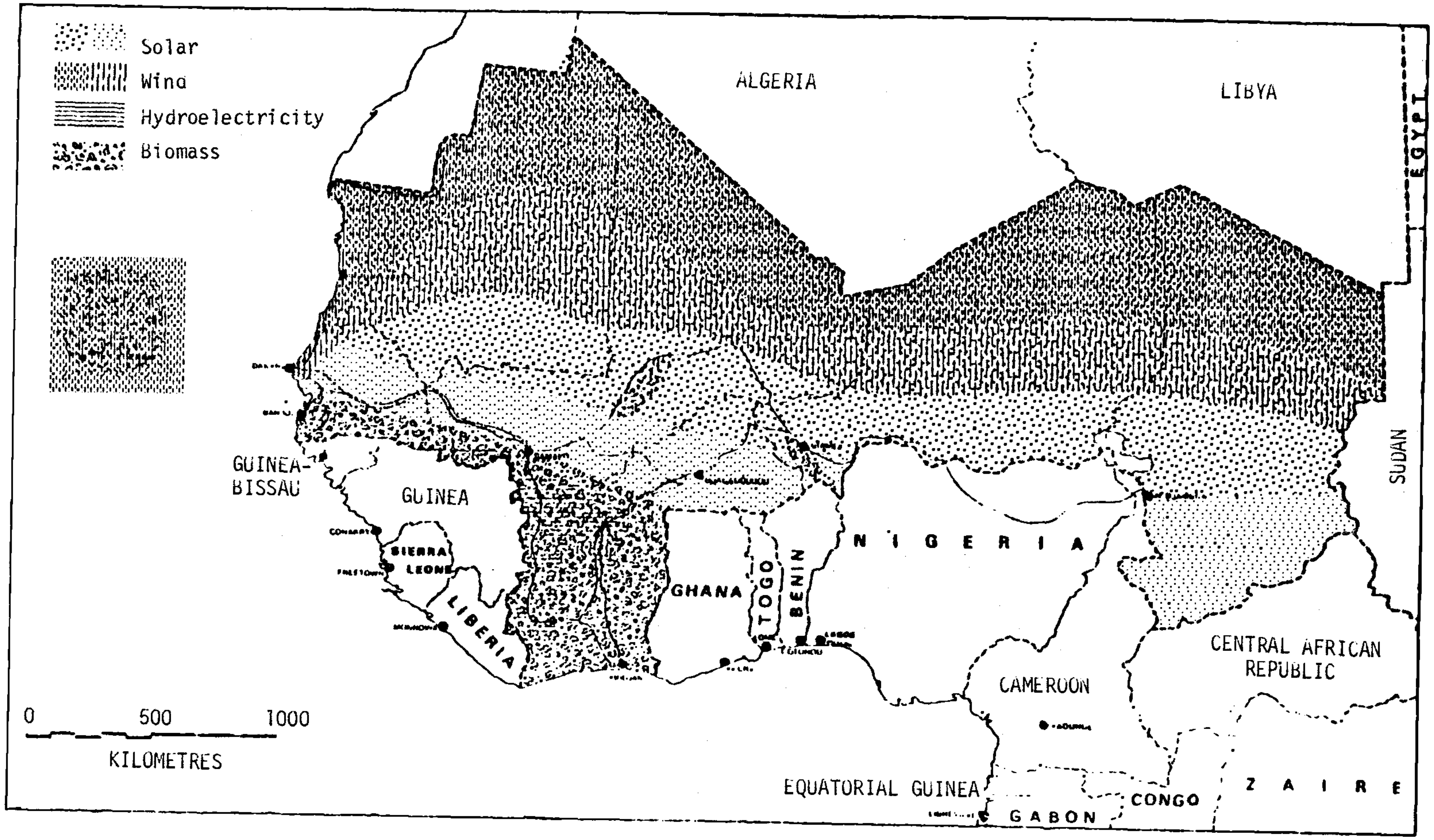

Fig. 5. Potentials to be exploited.

Table 8. Household needs in both rural and urban areas

Renewable energy solutions	Technical maturity	Adequacy of technology -- constraints	Adequacy of cost -- buying power	Observations
		Cooking, water heating, and house heating		
Improved stoves	Commercial	*** Use of traditional materials and techniques	*** Very low cost; could be built by user	Very significant impact on environment and energy balance; very low cost
Tree plantation (industrial or by villagers)	Commercial	*** Problems of land availability and forest management	** Heavy investment; would pay off in long term	Essential for regional ecological balance
Improved kilns for charcoal manufacture	Commercial	** Craft activity; work site mobility; training	**	Significantly improves carbonization performance
Vegetable waste briquettes	Commercial	** Possible only through agroindustries	** Price is competitive with wood in towns	One unit is operating in Gambia
Biogas	Commercial	** Presupposes water and manure availability in addition to waste; management problems	* Plant installation still too expensive	Direct combustion of vegetable waste easier for user; might be considered for community use
Solar stoves	Pilot	* Awkward to use; not well accepted	* Cost is too high	Might be considered for small communities
Vegetable "coal"	Pilot	* Complex manufacture, but well accepted	** Favourable prospects	Might be manufactured by agroindustries
		Drinking water		
Manual or foot pumps	Commercial	*** Easy to use, well accepted	*** Moderate cost	Small communities

Table 8 continued

Renewable energy solutions	Technical maturity	Adequacy of technology -- constraints	Adequacy of cost -- buying power	Observations
Multiblade windmill for pumping	Commercial	*** Reliable; easy to use	*** Moderate cost for good peformance	Well adapted to small communities
Photovoltaic solar pumps	Commercial	*** Well accepted; reliable; superior to diesel	** Investment cost high, but recurring expenses very low; increasingly competitive with diesel	Well adapted to large villages with high water consumption
Desalination units	Pilot/Commercial	** Variable according to technology used; maintenance problem	* Cost is generally very high	Would appeal to communities without fresh water
Lighting (outside distribution network)				
Biogas	Commercial	** Requires water, manure, and waste; management is important	** Could be justified on the basis of lamp-oil price	Lighting quality
Photovoltaic lights	Commercial	*** Very easy to use	** Price is still high; expected to drop substantially	Attractive solution where electric power distribution is not available
Food preservation				
Solar dryers	Pilot/Commercial	** Simple, fairly good acceptability	*** Low cost; rudimentary dryers could be constructed by users	Avoid waste of products

Table 8 concluded.

Renewable energy solutions	Technical maturity	Adequacy of technology -- constraints	Adequacy of cost -- buying power	Observations
Other needs: health, education, and communications				
Photovoltaic systems	Commercial	*** Simple, reliable	*** Competitive, compared to other solutions	For vaccine refrigeration, TV sets, telephone, etc.
Solar distillers	Commercial	*** Simple	*** Competitive	Distilled water for cell batteries and clinics
Secondary centres electrification				
Hydroelectric miniplants	Commercial	*** Very easy to use	*** kW.h cost production a positive factor	Falls should be well adapted for use and not far from consumers; scarcity of sites, except in Ivory Coast
Solar-photovoltaic miniplants	Commercial	*** Easy use	** Still too expensive, will drop in long term	Could work in small communities with low
Thermodynamic solar	Pilot	* Very complex	* Still too expensive	
Diesel plant with gas generator using vegetable waste	Commercial	* Fairly complex	** Cost per kW.h a positive factor	Possible in the vicinity of agroindustries or forest yards
Wind generator	Commercial/ Pilot	** Fairly simple, reliability not well known	** Competitive in windswept areas	

*** Very favourable; ** favourable; * unfavourable.

Table 9. Needs linked to rural production

Renewable energy solutions	Technological maturity	Adequacy of technology -- constraints	Adequacy of cost -- buying power	Observations
		Field manuring		
Biogas	Commercial	** Importance of handling	** Residues show some positive value, as compared to imported fertilizers	Not too much in use, except in Asia
		Irrigation, truck farming		
Gravity irrigation (small dams)	Commercial	*** Very simple to use, safe (no motor)	*** Investment cost for construction still moderate; no costs for pumping	Solution to be promoted, whenever practicable
Multiblade windmill	Commercial	*** Reliable, easy to use; tank required	*** Moderate cost	Well adapted to small areas (truck farming)
Photovoltaic solar pump	Commercial up to 10 kW	*** Very easy maintenance	** Still expensive, cost decline expected in medium term	Well adapted to small areas
Biogas + powered pump	Pilot	** Rather heavy management	*** Might be economical if biogas and residue are given value	Residues of potential value as fertilizers
Generator gas-powered pump	Pilot	* Rather complex maintenance	** Positive prospects	Possible on large land holding in a proper setting
Thermodynamic solar pump	Pilot	* Rather complex maintenance	* Still very expensive	Channel to be followed irrespective of constraints

Table 9 concluded.

Renewable energy solutions	Technological maturity	Adequacy of technology -- constraints	Adequacy of cost -- buying power	Observations
		Motorization (agriculture and craftsmanship)		
Charcoal-powered gas generators	Pilot	** Very simple design	*** Good profitability prospects	Well adapted for tractors and trucks
Vegetable waste-powered gas generators	Pilot/ Commercial	* Rather complex	** Interesting prospects	Powerful stationary engine for agro-industry
Photovoltaic microplants	Commercial	*** Very simple use	** Still expensive	Well adapted to low power needs (mills)
		Produce preservation (crops, fodder, and fish)		
Solar drying	Pilot	** Fairly simple, training necessary, some acceptability problems	** Substantial reduction of produce waste	Channel to be followed
Thermal solar cold (adsorption or absorption)	Pilot	* Complex, reliability to be proved	* Profitability still uncertain	
Photovoltaic thermal cold	Pilot	*** Rather simple systems	* Very high cost	

*** Very favourable; ** favourable; * unfavourable.

Table 10. Needs of modern sector

Renewable energy solutions	Technological maturity	Adequacy of technology -- constraints	Adequacy of cost -- buying power	Observations
		Hot water, sanitary equipment		
Solar water-heater	Commercial (regionally manufactured)	*** Easy to use, limited maintenance	*** Very competitive compared to electricity	
Heat exchangers	Commercial	*** Current technology	*** Very competitive for hotels and buildings	Heat is extracted from air-conditioning
		Air conditioning		
Passive air-conditioning	Commercial	*** Architects and users to be educated	*** No operating expenses	Use of traditional materials and technologies
Air humidifier	Commercial	*** Very simple, limited maintenance	*** Consumption 10% that of an air conditioner	For dry climates only; could be photovoltaic
Solar air-conditioning through adsorption	Pilot	* Complex	* Costs probably high	
		Transport		
Ethanol, plain or gasoline blended	Commercial	** Fairly complex	*** Vegetable material is expensive	Alternative use of resources: food or feed
Methanol, plain or mixed	Pilot	* Very complex	** Might be economical	

Table 10 concluded.

Renewable energy solutions	Technological maturity	Adequacy of technology -- constraints	Adequacy of cost -- buying power	Observations
		Energy for industry		
Solar collectors, plane or concentrators	Commercial	** Flat collectors are very easy to operate	** Might be profitable in some agroindustries, textile plants, etc.	
Vegetable waste-fired furnaces	Commercial	* Complex	*** Profitable in agroindustries with power and steam requirements	
Vegetable waste-fueled gas generators	Commercial/ Pilot	** Fairly complex	*** Very favourable prospects	A diesel engine could be operated using poor gas
Methanization of agro-industrial and urban waste	Commercial	** Fairly complex, maintenance problems	** Economical solution in certain contexts	Effluent purifying, although a secondary problem, is still important

*** Very favourable; ** favourable; * unfavourable.

RENEWABLE ENERGY IN DEVELOPING COUNTRIES: RESULTS AND FUTURE PROSPECTS IN SENEGAL

Djibril Fall*

Energy Situation

In considering the energy situation in developing countries, three points are basic:

- Developing countries that import oil have severe balance of trade difficulties;

- Wood consumption has reached a critical level and the threat of desertification is an increasingly serious problem: development of the most barren rural areas is seriously compromised even where vigorous measures have been taken; and

- After the first oil crisis of 1973, which marked the end of the era of cheap, plentiful energy, interest in the use of renewable energy became a virtually world-wide phenomenon. This led to better equipment for the development of nonconventional sources of energy.

Technological progress in the field of renewable energy has been very slow, even in countries that, before the oil crisis, had appreciated the role that renewable energy could play in meeting certain energy needs. This slowness may be explained not only by the fact that local financial resources were very modest, particularly in developing countries, but also because of the lack of a sense of urgency on the part of the more developed countries to support various efforts. Today, we are more aware that the development of renewable energy requires considerable financial investment and an adequate number of technical and scientific specialists. Moreover, in some situations, technologies that have not been fully tested and are not yet cost-effective must be used.

However, it should be emphasized that socioeconomic studies in several developing countries have clearly revealed that the energy development models that have been applied to date, and which have often been based on those of industrialized countries, have proved to be highly inappropriate. Most people in developing countries live in a rural milieu, in village structures often requiring small-scale energy decentralization. To obtain fuel supplies, people encounter problems posed by long distances, poor road conditions, and inadequate means of transport, thus the interest in using a local energy source. It is very important, therefore, for these countries to establish a policy for renewable energy exploitation on the basis of a master plan that outlines priorities. They must then assess the opportunities that are likely to be implemented and make them part of an overall energy strategy.

Although foreign aid is still indispensable to them, developing countries should try, as with any transfer of appropriate technology, to promote endogenous techniques that make better use of local resources and can be managed by the people most directly involved.

Energy needs

Four priority sectors must be considered for energy needs: firewood, water movement, food preservation, and rural electrification.

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Wood consumption

Wood is mainly used for cooking. Population growth and wood consumption forecasts for the next few years suggest there is a danger that forest resources will be unable to meet the needs, even in the very near future, unless vigorous action is taken immediately. Such action should include reforestation and development of local resources (e.g., the massive distribution of improved stoves in countries with limited forest resources).

Water pumping in rural regions

Typical diesel-engine pumping systems pose many problems, including fuel supply and increased maintenance needs. Current research and development in solar- and wind-energy applications should be continued and increased.

Preservation of foodstuffs

This is one of the most important conditions to be met for food self-sufficiency. Drying by sunlight appears to be the best process. Traditional drying processes (mainly for fish) that have produced only mediocre results (too short a preservation period and unsanitary conditions) could be replaced by simple, inexpensive and fairly functional equipment developed from local materials.

Rural electrification

Together with continued oil research, where it is justified, biomass use must be developed and evaluation of solar-station performance should continue (photovoltaic for small and medium capacities, as well as thermodynamic and wind) and pilot projects on hydraulic micropower stations should be actively pursued. Development of rural areas will depend greatly on how these activities are combined with rural electrification. These areas could also lose their "isolated" status as a result of the development of means of communication and a more functional literacy program offered through educational television.

Renewable Energy and Potential

Most developing countries have yet to assess their solar and wind potential. Applications undertaken in these countries in terms of the use of renewable energy have not always adequately considered local problems and more or less favourable factors such as the amount of solar radiation or wind speeds.

One of the first things to be done is to establish a network of carefully maintained and operated measuring stations.

Solar and wind energy

For water movement

Water movement falls into three categories: village water supplies, water for livestock, and irrigation for crops. Each of these categories has different characteristics and requirements.

Village water supply -- The quantity of water to be provided ranges from 20 to 30 m^3/day, which requires an installed capacity of 3-5 kW. Results so far indicate that photovoltaic motor-driven pumps, or pumps operated by wind-driven generators or windmills, appear adequate. The equipment is still being tested and, if the predictions that costs will decrease are borne out in the next 5 years solution to compete with classic pumping methods used in these areas.

As part of the overall thrust to provide potable water, efforts involving the treatment of brackish water could be conducted using equipment operating on the principle of inverse osmosis and associated with a solar-powered motor. The performance of such equipment as compared to classic pressure distillers currently in use is very interesting and worth investigating further.

Water for livestock -- An installed capacity of 30 kW is needed to set up water points able to meet the needs of herds of cattle owned by many small villages that are relatively close to one another. Particularly in the Sahel, this application is of the utmost importance and could even prove to be economically viable when compared to traditional pumping methods. Existing water points are fed by solar-powered or wind-powered devices (both of about 1-5 kW). The increased number of such water points has created maintenance and repair problems.

Irrigation for crops -- The current capacity used in some developing countries ranges from about 20 to 100 kW for solar-energy applications. There are also plans to establish pumps driven by gas-generating devices fed with plant, and more specifically agricultural, wastes.

For heat production, refrigeration, and passive air conditioning

Heat production includes both hot water by solar water heaters and hot air by solar dryers. In both cases, the equipment could be manufactured locally in many countries. Today, the solar water heaters are used mainly for domestic needs (cities) and for group use: hotels, dispensaries, etc. in rural and urban areas. These devices have just started to be marketed.

Solar dryers are used to preserve foodstuffs by solar drying, which is superior to traditional methods in terms of yield and hygienic conditions.

The reliability and economic value of refrigeration methods based on solar power require further testing.

Today, solar architecture offers a broad range of concepts for passive air conditioning that appear to have been inspired by rural village huts. These designs are based on old techniques that use local materials and integrate environmental features.

Today, these ideas have inspired many architects, engineers, and physicists. The concrete dwellings and buildings resulting from models hastily designed soon after independence was achieved are very unsuitable today, particularly in light of the economic crisis, and more particularly the energy crisis that countries in their third decade of independence are experiencing.

For cooking

Experiments with solar stoves in Africa have not been as successful as had been hoped and use of these devices should be reviewed and adapted to certain constraints. The heat regulation system should require very little involvement on the part of the user. Moreover, efforts should be made to avoid overly disturbing certain cooking customs (some dishes must be cooked over a small fire). In addition, daylight hours do not always correspond to the hours when family meals are traditionally prepared.

Biomass energy

According to information from essentially agricultural countries, agricultural wastes may be possible sources of energy. A strategy should be established to develop such wastes, at the same time ensuring that the soil retains the elements that it needs to remain fertile and that animals continue to have access to sources of food. Biogas experiments using animal and plant wastes are currently underway in rural areas and biogas appears appropriate for cooking wherever plant and animal wastes are easily collected.

Today, in the Sahel, better management of the limited forest resources is a national imperative. These countries are attempting to improve stoves so that firewood can be used more rationally and, at the same time, to implement a reforestation policy. They are also using more modern methods to produce charcoal.

In the Sahelian countries, an increasing number of improved stoves, constructed from local materials (usually clay and sand) by the rural inhabitants themselves, are being distributed. These improved stoves enable the users to reduce their consumption of firewood for cooking by 40-50%. If massive distribution is undertaken now, it could, in the long run, be very important in terms of better forest resource management through the fight against deforestation.

Energy from biomass could also play a very important role in developing countries. Mechanical energy needs (water pumping and milling of grains), electrical energy needs (electrical-power stations powered by poor-gas), and liquid fuel needs (methanol) could be fairly well satisfied through exploitation of, for example, eucalypt plantations.

Hydroelectricity

It is recognized that Africa contains about one-third of the world's hydroelectric potential, even though this potential is very unevenly distributed throughout the continent. A number of African countries are being examined as possible hydroelectric sites, because it could be very advantageous for hydroelectric microstations to supply the small, isolated electrical networks.

Although lighting is not considered a major priority, it is generally recognized that rural development is closely linked to this problem.

Isolated rural areas will still have a long wait before they receive electrical energy from the classic distribution network. However, solar energy can play an indispensable role here and now: for lighting, supplying rural educational television, independent energy sources for bush dispensaries, telephones in rural areas, radio-relay systems, etc. It is very likely that in certain rural areas today, solar electricity is economically competitive with electricity produced from classic diesel-driven systems.

All the opportunities that hydroelectric microstations offer should, of course, be exploited before thermodynamic or photovoltaic systems are considered. In many instances, however, only these two methods offer interesting prospects when wind energy is not cost-effective because of unfavourable wind patterns.

Geothermal energy and energy from the ocean thermal gradient

As far as we know, the best known geothermal potentials in Africa today exist in Ethiopia, where studies have been conducted for several years.

Experiments in Ivory Coast on the exploitation of energy from ocean thermal gradients have not yet resulted in practical applications.

Objectives of an Energy Development Plan

In the preceding pages, the energy situation and renewable energy potentials have been described, as well as the techniques that should be promoted to exploit these types of energy. However, this is conceivable only within the framework of an action plan that takes into account both the role that so-called conventional energy sources continue to play and the possibility of replacing them with renewable energy sources to meet specific energy needs (technical-economic comparisons). The action plan must contain a description of these needs and evaluate energy substitution potentials as well as the technologies available for their utilization. It must also integrate cost problems and their evolution in relation to the techniques established or promoted. Thus, decision-makers may avoid courses of action whose results are too uncertain because certain guarantees were not made at the outset with regard to the sometimes spectacular technical aspects that are often promoted by suppliers concerned only with selling their products.

One of the first tasks in drawing up the action plan is to prepare a summary of experiments and applications in the renewable energy field. Emphasis should be placed on the circumstances surrounding the project, the successes and problems encountered by operations already conducted or in progress, actual performance, life-expectancy forecasts for the equipment used, financial costs, the attitudes of local inhabitants vis-à-vis the projects, and their degree of involvement.

Next, because of the paucity of information available on solar and wind potential data, biomass resources, and sites that would be favourable for the exploitation of hydraulic energy, a series of activities (construction and operation of measuring stations) should be undertaken to help predict the size and location of preferred construction sites for processing branches built as part of pilot operations. All this, however, presupposes the promotion and organization of research in the country involved so that contact may be maintained with research and new discoveries in other countries. This raises the problem of training researchers, engineers, and technicians and placing them in the appropriate institutions with a status high enough to have an incentive effect.

The countries concerned may thus keep abreast of the technological situation, so that when the time comes, they may choose equipment wisely. The equipment must be specifically adapted to the local environment and local needs by being progressively oriented (if possible) toward the development of prototypes for the preindustrial stage. It should meet the following requirements: use of local materials, satisfy priority energy needs, and consider the purchasing power of the population and the possibility of local maintenance.

Activities Conducted in Senegal and Future Prospects

The centres involved in research and applications of new and renewable energy in Senegal as well as demonstration projects on renewable energy that have been completed or are still in operation are listed in the appendices.

Commercial energy

Research has been conducted on electricity; hydrocarbons for industry, transport, and supply for urban centres; and wood and charcoal sold in towns for cooking.

Rural needs

Several topics have been worked on. They are: water and energy needs; water supply (village and pastures); agricultural activities (including milling of grains and preservation of foodstuffs); promotion of local crafts; transport-related activities; cooking needs; lighting; and motorized fishing.

Energy consumption in Senegal

Annual consumption of wood averages 1 m^3 per person. For a population of 6 million, this is the equivalent of 1.4 million tonnes of fuel (64% of total energy consumption). Internal oil consumption is 0.8 million tonnes (36% of total consumption).

By the year 2000, energy needs from firewood will have doubled for rural areas and tripled for urban. Consumption of electricity will double every 10 years. Note that electricity production absorbs 30% of imported oil products.

Urgently required activities currently in progress

Massive distribution must be carried out for the improved "Ban ak suuf" stoves completed at the Centre d'études et de recherches sur les énergies renouvelables (CERER).

Other activities include: large-scale reforestation; development of peat and peanut-shell resources; project for distribution of methanol digestors; use of biogas in thermal engines; exploitation of hydroelectric potential; and continued research on oil.

Solar energy

As a result of the research and applications conducted for the past 17 years at CERER, solar dryers have been established in fishing cooperatives. These dryers are expected to be cost-effective in the next 3 or 4 years.

Solar water heaters are economically viable and marketing has been undertaken by the Société industrielle pour l'application de l'énergie solaire (SINAES).

Studies are underway in cooperation with architects to develop refrigeration to preserve medication in rural health-training units and passive air conditioning designs in urban and rural dwellings.

Pilot projects are being conducted on solar production of distilled water and treatment of brackish water.

A number of water pumping stations have been established in rural areas. They are based on the thermodynamic method using prototypes developed at IPM-CERER, in the early 1960s and on photovoltaic and wind methods. Scientific follow up will be done by CERER but at present there have been maintenance problems.

Conclusion

There is a growing interest in solar energy with the recent inauguration in Senegal of two power stations (solar in Diakhao, aerosolar in Naigawolof) as part of the rural electrification program, and with the establishment of programs in other developing countries. In their integrated projects, national-development programs are giving more importance to the use of renewable energy, and efforts have been made to establish national and sometimes regional structures (for example, Centre régional d'energie solaire, CRES, in countries of the Communauté économique de l'Afrique de l'ouest) and to make scientific and technical managers aware of the need to promote appropriate technology.

However, for any of these activities to be effective, they should be able to rely on international cooperation: Unesco, UNDP, UNIDO, UNEP, ILO, WMO, WHO, and IDRC, to name but a few of the international organizations participating in the implementation of certain specific programs for renewable energy applications. Their activities should be broadened and better coordinated. Likewise, current bilateral cooperation programs between countries should be better exploited.

The era of renewable energy used for the benefit of the most disadvantaged countries may then become a reality before the end of the 20th century.

Appendix 1: Centres for research and applications in new and renewable energy[a].

Operator	Sponsor	Sector	Mission
CERER	Université de Dakar (MESRS) and SERST	Research and development	Evaluation of solar and wind potential Development of solar technology prototypes Scientific follow-up of solar- and wind-powered installations Solar heating, pumping, distillation, and drying Passive air conditioning Use of biomass (improved digesters and stoves) Massive distribution of improved stoves in rural areas
Faculté des Sciences	Université de Dakar (MESRS)	Basic research, researcher training, teaching,	Photovoltaic cell research; experiments
ENSUT (ex IUT)	Université de Dakar (MESRS)	Training and applied research	Training of specialized technicians and engineer-technologists Development of windmills and photovoltaic experiments

Appendix 1: Concluded.

Operator	Sponsor	Sector	Mission
EPT	MESRS and MFA	Training and applied research	Training of engineers; windmill and biogasification experiments
SINAES	MDIA	Industrial and commercial	Studies and engineering; development, establishment, and maintenance of solar and wind equipment
SENELEC	MDIA	Industrial and commercial	Experimentation with solar power stations
ITA	SERST	Research	Food technology: preservation by solar drying
ISRA	SERST	Research and development	Experimentation in agricultural production; energy from agricultural wastes

[a]Abbreviations:

CERER -- Centre d'études et de recherches sur les énergies renouvelables; **ENSUT** -- École nationale supérieure universitaire de technologie; **EPT** -- École polytechnique de Thiès; **ISRA** -- Institut sénégalais de recherche agricole; **ITA** -- Institut de technologie alimentaire; **MDIA** -- Ministère du développement industriel et de l'artisanat; **MESRS** -- Ministère de l'enseignement supérieur et de la recherche scientifique; **MFA** -- Ministère des forces armées; **SENELEC** -- Société sénégalaise de distribution d'électricité; **SERST** -- Secrétariat d'État à la recherche scientifique et technique; **SINAES** -- Société industrielle pour l'application de l'énergie solaire.

Appendix 2: **Completed renewable energy demonstration projects in Senegal.**

Site[a]	Characteristics and application and projected operational date	Cost in millions of CFA and source of financing	Status
Méouane (th) Mérina Dakhar (th) Niakhène (th) Diaglé	Thermodynamic solar pumps with flat-plate collectors (1 kW, SOFRETES), village hydraulics, 1976	42 FAC	The four pumps are first generation. They present maintenance problems and are constantly out of order
Baback (di)	Photovoltaic solar pump (1.3 kW, Guinard pumps), village hydraulics, 1978	8	Out of order
Aéré Lao (ri)	0.9 kW photovoltaic solar pump (Guinard pump), village hydraulics, 1979	10 FED, SOS Sahel	Functions normally
Saou (th) Mbodienne (th) Keur Bacar (th) Diaglé (ri) Mbidienne Mouride (ri)	Savonius windmills (SINAES - IUT), village hydraulics, 1977-78	18.5 FAC	All Savonius windmills have had operating problems. A program to repair some of them should begin in 1983
Louly Bentégné (th)	1 kW wind-driven generator (aerowatt), village and irrigation hydraulics, 1981		Functions properly
Bambey (di)	0.9 kW photovoltaic solar pump (Guinard pumps), drip system irrigation, 1978	10 FAC	Functions properly

[a] th - Thiès region; di - Diourbel region; ri - River region.

Appendix 3. Renewable energy projects in development stage.

Title of project	Projected operational date	Projected cost in millions CFA and planned source of financing	Status
Photovoltaic power station for refrigeration in the Kalounayes	1983		
Photovoltaic pumping stations in the Diaglé region Three 1.5 to 2 kW stations are projected	1983	40 FAC - AFME	Formerly planned for Mboumba, this project will replace Diaglé's thermo-dynamic pump and windmill. The three stations to be built during first half of 1983
Photovoltaic power station for electricity production in Dahra - 24 kW	1983	165 FAC - AFME	Feasibility study will begin in March 1983
USAID project - renewable energy phase II CERER - ITA - Waters and Forests, SINAES	1983	105	Project underway in 1983
25 kW photovoltaic pump	1983	158	These four projects are grouped together for a total cost of 430 M CFA (plus a 20 M CFA project at CERER). Studies will begin in March 1983. Information available in October 1983
Electricity-producing power station, through biomass gasification	1984	164	
Feeding of rural dispensaries with renewable energy	1983	40	
Water pumping in the Niayes using wind energy	1983	48	
Maintenance of solar and wind stations	1982	25 FNE	Budget allocated to SINAES. The maintenance program began with Mérina-Dakhar, Kanel and Thiangaye

Appendix 4. Renewable energy projects in operation.

Name of project[a]	Characteristics and application - projected operational date	Cost in millions CFA and source of financing	Status
100 kW thermodynamic power station	Concentrated, solar, thermodynamic electricity production, 1986	2400	
9.5 kW experimental energy centre in Niagawolof	Solar, photovoltaic (photowatt) and wind-driven generator (aerowatt) electricity production, December 1982 4.5 kW bipolar wind-driven generator and 5 kW photovoltaic generator	139 PNUE AFME SENELFS	Centre completed in January 1983 Functions normally
Bakel Station	Solar, thermodynamic, flat-plate collectors (SOFRETES) and thermo-electric pumping for irrigation, 1977-82	300 FAC USAID	Major delay (station too small) Reorientation study in February and March 1983
SINAES industrial project in Thiès	Industrial unit, manufacturing of solar water heaters, 1983	350 Government of Senegal FED SINAES	
Mont Rolland Catholic mission (th)	0.5 kW SOFRETES photovoltaic pump village hydraulics		Has had maintenance problems and is now under repair
Bondié Samb (ss)	Thermodynamic solar pump with flat-plate collectors (10 kW SOFRETES) village hydraulics, 1980	80 FAC BNE	Functions properly. Reservoir and surface equipment not yet installed
Mérina Dakhar (th)	1.8 kW SOFRETES photovoltaic, with thermodynamic pump, 1980	SOS Sahel	After a year-long engine breakdown, this installation now functions properly
6 villages in the Mbour region (th)	2.6 kW photovoltaic solar pumps and Guinard drip system irrigation pumps, 1980 (3)	108 FED Caritas Senegal	These pumps operate but do not perform to standards
Louly Ngogom (th)	4 kW wind-driven generator (aerowatt) for drip system irrigation, 1981	21 FAC Caritas Senegal	Functions properly

Appendix 4 concluded.

Name of project	Characteristics and application - projected operational date	Cost in millions CFA and source of *financing*	Status
Diakhao (ss)	25 kW SOFRETES thermodynamic power station with flat-plate collectors for electricity production, 1981	375 FAC CCCE SENELEC	This power station has been operational since early 1982, but does not perform to standards (50% less)
Mboro (th)	4 kW wind-driven generator (aerowatt) for drip system irrigation and provision of electricity, 1981	34 FAC	Functions properly
Affiniam (ca)	0.6 kW photovoltaic Guinard pumps for village hydraulics, 1981	FED	Functions properly
Mont Rolland (th)	0.7 kW photovoltaic (Leroy Somer) system supplying dispensary with electricity, 1982	8.5 FAC COMES	Functions properly
Kanel	1.8 kW photovoltaic (SOFRETES) for village hydraulics, 1982	SOS Sahel	Functions properly
Thiangaye	1.4 kW photovoltaic (SOFRETES) for village hydraulics, 1982	COMES - CIMADE	Functions properly, inaugurated in January 1983

[a] th - Thiès region; di - Diourbel region; ri - River region; ss - Sine Saloum region; ca - Casamanca region.

SOLAR ENERGY IN THE TROPICS[1]

Jose Fernando Isaza*

Almost all energy transferred over the surface of the planet has a solar origin. Only the very small fraction that comes from tidal, nuclear, and geothermal sources has a different nature. In the context of this paper, however, the term solar energy refers only to the direct conversion of solar radiation into "human forms of energy" such as usable heat or electricity, and excludes such sources as hydroelectric power (gravitational energy produced by the evaporative cycle of water), wind energy (kinetic energy produced by the expansion of air), and fossil energy (accumulated during millions of years in coal, oil, and gas). In this context, even such forms of energy as biomass, both in its traditional form of wood or in the more developed applications (biogas, pyrolysis, methanol, etc.), are not included into the restricted definition.

Of the many ways through which solar radiation can be transformed into usable energy, two are of importance today: conversion into low temperature heat and conversion into electricity. However, from the economic standpoint, there are major differences between the application of solar energy in heating and electrical end uses.

The low temperature heat application has total costs (including fixed and variable) that are smaller than those resulting from the use of hydroelectricity or fossil fuels. However, the production of electricity, especially through photovoltaic cells, has costs 10 times greater than those found in the conventional generating technologies despite the great reduction in the production costs of photovoltaic cells over the last 5 years, and even those that can be expected in the near future.

In 1977, the cost of a peak photovoltaic kilowatt was estimated as $16000; in 1979, it was around $10000; and the current price (1982-83) is as low as $8000.

The conversion of solar energy into electricity through thermodynamic cycles also has costs that surpass by several times the total cost of the conventional alternatives. For example, in the most recent and efficient installations in the Mojave Desert in California with 300 clear days/year, the installed cost is $14000 per peak kW.

By contrast, the solar collector system necessary to replace a continous kilowatt of electricity in the tropics has a total installed cost in the order of US$770. The continuous, distributed, hydroelectric kilowatt has costs in the order of US$2290, and the equivalent[2] peak kilowatt costs US$1235. Another big difference that must be accounted for is that the total energy balance of the photovoltaic cell is negative when the energy used in its production is compared with the total amount of electricity generated over its life span. For the Colombian solar collector, however, with a usable life of at least 20 years, the energy used in its manufacture from raw materials is recovered in less than 18 months.

The principal research and development efforts are directed today to reducing production costs of the photovoltaic cells, and to designing adequate technologies for mass production and installation of solar collectors, particularly in houses that are already built. The economics of tropical air conditioning, especially in the low and humid tropics, is another line for future development.

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[1]The author wishes to acknowledge the collaboration of Dr Jorge Zapp, Technical Director of Las Gaviotas Centre.

[2]A factor of 0.52 is used to convert peak kilowatts into continously generated kilowatts.

In the context of this paper, the actual contribution of solar energy to the energy balance of the world population is estimated as only 0.1%, but by the year 2000 it may rise to between 1 and 3%. The new trends of oil prices could displace this estimate to the lower value. Even in this condition, its contribution could be an oil equivalent of $1.5\text{-}2 \times 10^9$ barrels/day -- an amount that corresponds to the actual production of the North Sea oilfields.

Solar Energy in the Tropics

Although much has been written about the subject, few efforts have been made to use solar energy in the tropics. Generally, it is not possible to reach definite conclusions from the limited number of projects. The Colombian experience deserves special attention because it is one of the few instances of large-scale use of solar energy in the higher and lower tropics.

Tropical needs

In the tropics, many applications of solar energy are of a diffuse nature: for example, crop drying, water distillation, spray irrigation, or power supply in rural communications. However, the rapid growth of the cities has resulted in people living in hundreds or thousands of identical homes. Thus, in the high tropics, some large-scale applications of solar energy, such as water heating for domestic use, may prove advantageous.

Also, such factors as irregularities in public utility services favour "home-generation" of energy, even if it only covers a fraction of the domestic energy consumption.

Limitations

The low utilization of solar energy in tropical countries is apparently linked to several technological and economic factors:

- Because solar energy is a "free flow," its price depends mainly on initial investment, a limited resource in most tropical countries.
- Although many tropical countries already have facilities for basic research, their capacity for developing products for local conditions is almost nil. The use of solar energy in the tropics involves all aspects of technological creation.
- There is perhaps only one environmental restriction: the main use of solar energy sometimes coincides with periods of diffuse light during the rainy season (coffee bean drying, for instance).

The Tropical Challenge

In an environment where temperatures reach 30°C, with 8 hours of sunshine/day, an elementary low-temperature solar collector can be made using any pipe, tanks painted dark colours, or polyethene bags exposed to sunshine. Virtually all educational or research centres in tropical countries have built and evaluated one or more solar collector. Also, without exception, efforts to produce such "technology" on a large scale have been unsuccessful.

Basic researchers, regardless of their scientific level, have almost always failed in their attempts to mass-produce products that have been successful as handmade laboratory prototypes. What have their major errors been?

- Even in the short term, the service quality of the prototype product is very inferior to conventional alternatives and the life of the prototype is several times shorter than conventional alternatives.

- Experiments have generally not accounted for permanent modification of equipment elements, which are subject to cyclical changes in radiation, temperature, pressure, and humidity.

- It is very difficult to determine real prices, due to the small initial efforts involved, lack of knowledge about fundamental principles of industrial production, how to estimate cost of materials, poor work evaluation, and lack of knowledge about distribution and installation processes.

- Design efforts are directed, generally, to the energy-collecting element and less attention is paid to the rest of the thermal system, which is as important as the collector itself.

- Eventually, solar energy becomes a simple experiment in recreational physics conducted by back-yard experimenters. This makes it even more difficult to mass-produce units based on their cost and energy efficiency.

- Finally, solar energy must compete with other sources of energy, which are usually subsidized.

The Colombian Case Study: Solar Technology in Las Gaviotas Centre

Stage of technological oversimplification

About 12 years ago, researchers started building collectors at Las Gaviotas Centre, located in the western plains of the Orinoco River basin, to meet the hot-water needs of its rural hospital. Knowledge from four-season countries was transferred during the initial stage. It was soon evident, however, that these design parameters did not meet tropical needs and requirements. Later, in 1978, a bi-dimensional micro condensor was designed and installed to supply hot water to 550 apartments in the city of Medellin, located at an altitude of 1400 m (Villa de Aburra I Project). The negative and positive results of this experience can be summarized as follows:

- The collector was substantially more economical than any alternative transferred from four-season countries.

- The tropical design was limited to the collector. The concepts of tank, circulation, service and operating characteristics, etc., as used in developed countries, were adopted with only minor modifications.

- Most failures were due to the fact that pumping equipment made in Colombia was not suitable for hot water. The second most important cause of malfunctioning was poor maintenance of electronic control circuits by building electricians.

- Within only 2 years, water quality changed, and the carefully selected silicium-aluminum pipes started to corrode almost five times faster than expected.

- The real capacity of the system was reduced to less than half by daily rationing of electricity and drinking water.

- The principal source of problems was undoubtedly due to the adoption of an external pumping system that had worked acceptably in developed countries. Figure 1 shows the design process used in this initial project of Aburra I.

This project and the necessary modifications to the system clearly demonstrated that the design of a tropical water-heating system demands an integrated approach that considers all factors, ranging from local users' practices to the selective absorption of the collector layer.

Basic research was centred on developing circulation methods that do not require electric power and structuring all aspects of the solar water-heating process within a system that can be analyzed as a whole. Applied research programs stressed identification of materials, manufacturing processes, and a system suitable for installation in all tropical regions.

This first large-scale experience showed that the solar collector is only an isolated element of a system made up of many interrelated subsystems. It is difficult to optimize the total system because of the nonlinear performance of most of the elements within it.

In large and homogeneous markets, such as those in developed countries, the design of each component contributes to the optimum performance of the whole system. In the tropics, however, this kind of oversimplification does not work. Inadequate solutions are arrived at if minimizing the cost of materials is the only criterion adopted. Thus, although initial results from the Aburra I project greatly surpassed expectations, the limitations of the tropical environment soon started to affect the operation of the system, substantially reducing its life expectancy and capacity.

This clearly indicates that the design criteria and the number of elements included in the system of analysis (Fig. 1) had been insufficient. Furthermore, at that time (1980), no practical tools were suitable to "tropicalize" the partly defective system. It was decided, therefore, to gather the greatest possible amount of information from the 550 units in Aburra I, which would be used in the design of modifications and for future projects.

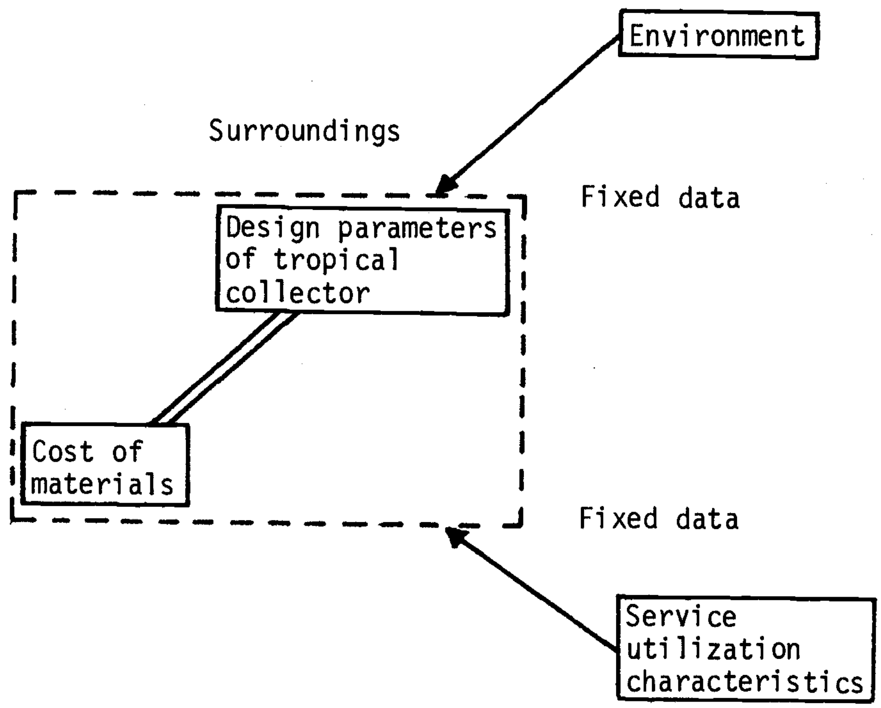


Fig. 1. Scheme of the design process for the Aburra I project.

Within 1 year of operation, the following decisions regarding the research plan were made on the basis of gathered data:

- Water circulation in the system must not depend on electronic control equipment or electricity. The system must be 100% solar -- combining electricity and solar power is not acceptable.

- The design must be economically feasible.

- The system's life, even under changing supply conditions, must be comparable to that of the houses.

- The system of analysis must include the greatest number of elements capable of variation, and must be adaptable to changing environmental characteristics.

Based on this experience, an approach was chosen incorporating the highest number of new variables related to this problem. However, the recirculation mechanisms, temperature, flow, and radiation controls, and the storage tanks, as used in four-season countries, were adopted without further study.

Internal and external elements were dealt with as follows:

- Geographical and geometric characteristics, such as latitude, altitude, and daily geometrical variations due to the relative astronomical position of the sun, were considered.

- Environmental characteristics were subdivided into two groups: (a) those depending on location, prevailing winds, daily temperature, etc.; and (b) those depending on seasonal variations such as diffuse and direct solar radiation. A statistical generation model was developed for the latter characteristics, although in most cases daily data from nearby meteorological stations were used.

- The system includes storage capacity data. Losses, consumption, and energy additions are related to collector, architectural, and environmental characteristics. An approximate value of the thermal capacity of the tank solids was also included.

- Architectural characteristics: regular operation depends on factors such as azimuth determined by the roofs, tank location, seasonal shadows cast by buildings, etc.

- External losses: an empirical function was developed that accounted for daily mean operating temperature, wind velocity, outside temperature, and geometrical characteristics of collectors, tanks, and pipes.

- Data gathered at Nueva Villa de Aburra I made it possible for the first time to define hot-water consumption patterns of a communal supply system. Statistics on the users' socioeconomic level were included, although this is an external value.

- Operating conditions were reduced internally to the efficiency characteristics of the collector, depending on internal and external temperatures and on radiation. The decision was taken to completely dispense with forced circulation systems (pumps, electronic control systems, differential comparators, etc.) and any external energy sources.

- Technician training: originally, the labour force was highly heterogeneous, ranging from technicians specialized in epoxy resins to technicians responsible for installing and maintaining the delicate integrated control circuits. A profound technological change was experienced and all technicians are now "solar plumbers". Their level of skills ranges from mechanical engineers with thorough knowledge acquired from their own research on thermosiphons to assistants who handle each element of the system. Manufacturing and installation activities were integrated, which made it possible for workers to interchange industrial and installation jobs. The addition of independent technologies brought together out of necessity is something of the past; this has been superseded by a new technological specialization with varying levels of skill.

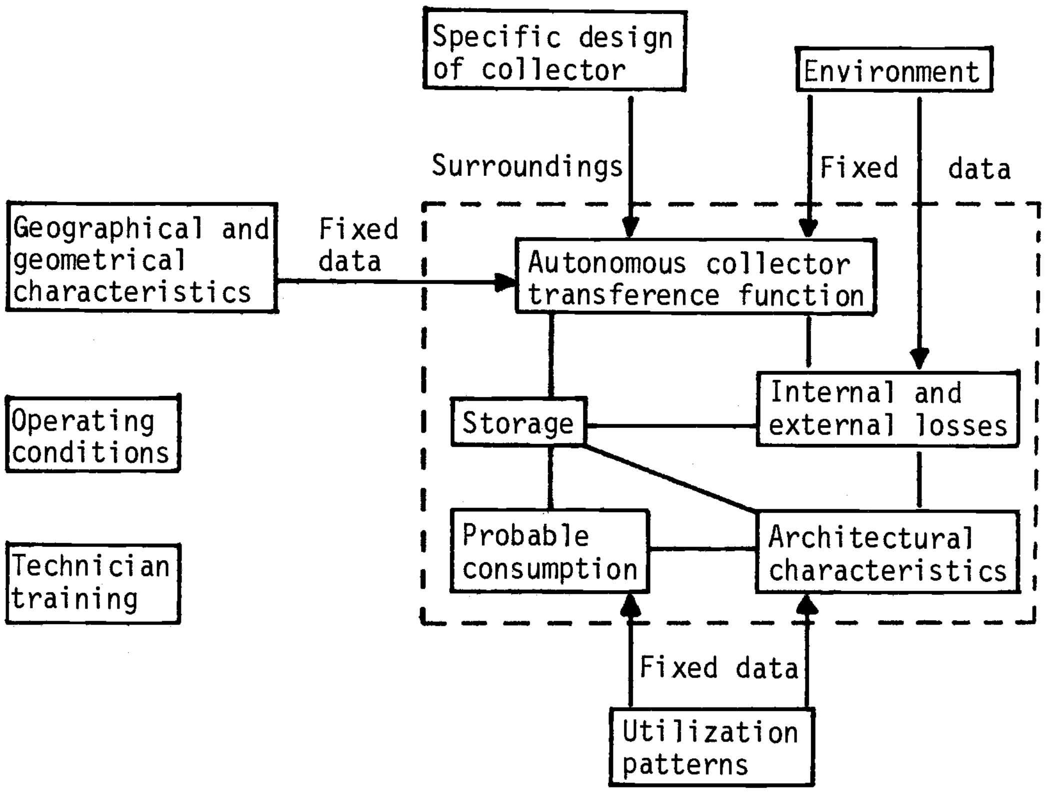


Fig. 2. Integrated system of analysis to simulate the operation of a water-heating unit for one or more years.

- The collector: because the cost of the system is not affected greatly by improving materials in contact with the environment or the liquid, copper pipes and anodized aluminum exteriors were adopted. Because design variables of the collector, such as number of pipes, surface selectivity, and internal insulation, are not typically gradual, in each simulation they were considered as fixed external data, corresponding to the measurements made with the prototypes. Thus, the collector was represented in the model as a polynomic function of the operating characteristics of various prototypes.

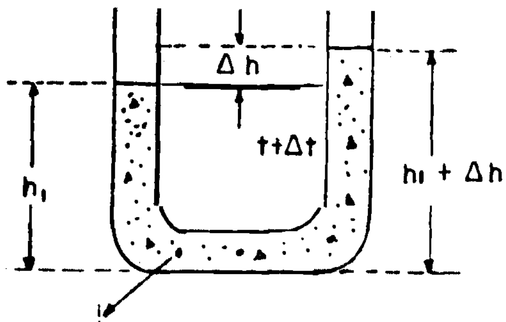
- General considerations: this new approach involves a unique and continuous energy-generation technology that does not depend on artificial operating policies determined by environmental conditions, water-use patterns, and storage-system condition.

Figure 2 schematizes the analysis procedure used. It was possible to arrive at such a simple model due to the unification of solar technology.

The Gaviotas thermosiphon

Background

Interruptions of utilities (electricity and water were rationed), their low quality (voltage variations exceeded internationally accepted standards), and substantial changes in the physico-chemical composition of water clearly indicated that solar heating systems must be self-contained. Environmental and social characteristics in the tropics also made it imperative to develop a technology that was well adapted to these regions.



$$\rho_1 g h_1 \quad t \qquad = \qquad \rho_1 (1 - \alpha \Delta t)\, g\, (h_1 + \Delta h)$$

Fig. 3. Thermosiphon principle.

The thermosiphon, based on small variations in water density when it is heated, is one of the few principles that met these requirements. Although bibliographic research on the thermosiphon showed that it is a well known principle, it soon became apparent that the technology necessary for its wide-scale utilization is practically unknown. Various problems had already been detected during experiments at Las Gaviotas Centre: flow inversion during the night, gas buildup inside the pipes, and difficulty starting the system in the morning -- the only problem researchers did not have to deal with was the risk of freezing. Models mentioned in the literature had almost all these disadvantages.

In the two branches of vessels in communication (Fig. 3), the density differences produced by a temperature difference, t, can be used to produce a flow when, and only when, there is such a difference in temperature.

The thermosiphon solar collector

As can be seen in Fig. 4, the principle of the thermosiphon solar collector is both elegant and simple; however, its applicability is not immediate.

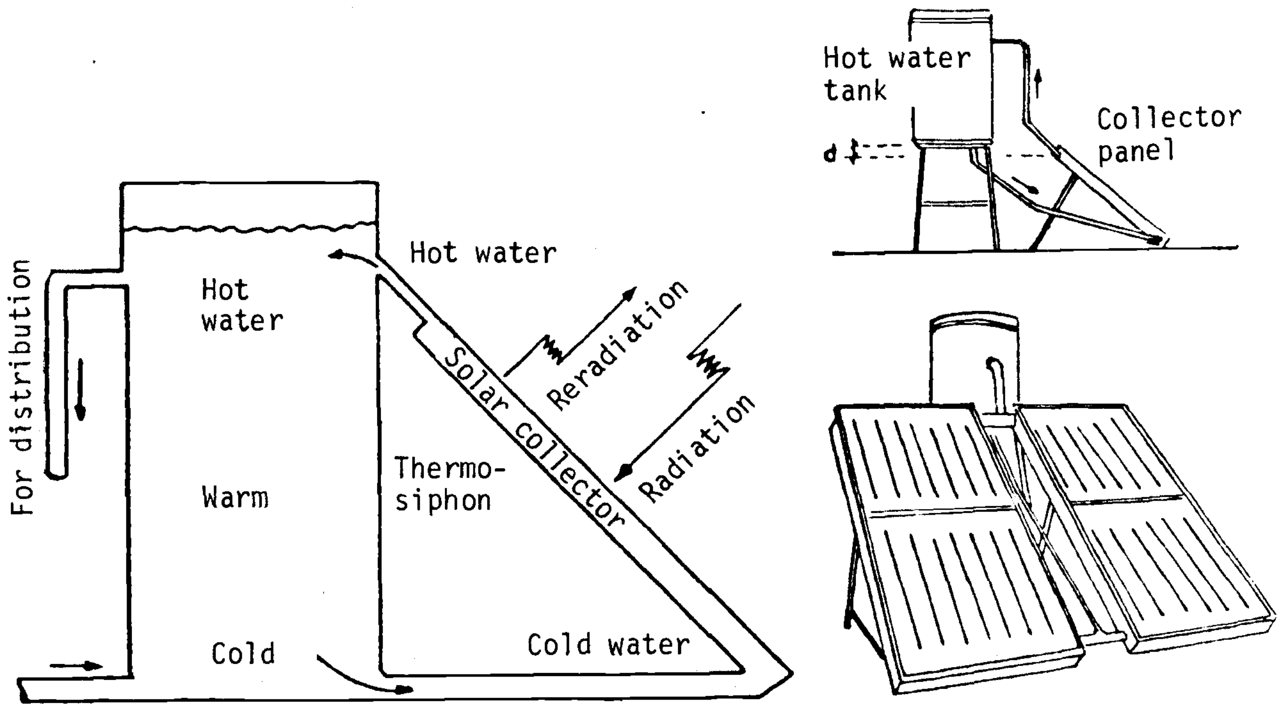


Fig. 4. Thermosiphon: schematic diagram and water heater.

During the night, the collector loses heat into the atmosphere, especially by infrared radiation. Because the average temperature of the water in the tank is higher, the desired process is reversed and the water heated during the day is cooled substantially during the night.

Because differences in pressure only amount to a few millimeters, conventionally designed collectors and pipes are not suitable for this process.

Tap water is high in dissolved gases, which are generally released when the water is heated. Consequently, gas bubbles obstruct the collectors, blocking the operation of the system.

The conventional thermosiphon can only be recommended for small-scale installation. Research conducted in Las Gaviotas Centre was directed to finding practical solutions to these difficulties, which limit the applications of the thermosiphon. To solve these limitations, a product called the macrothermosiphon was developed (Fig. 5).

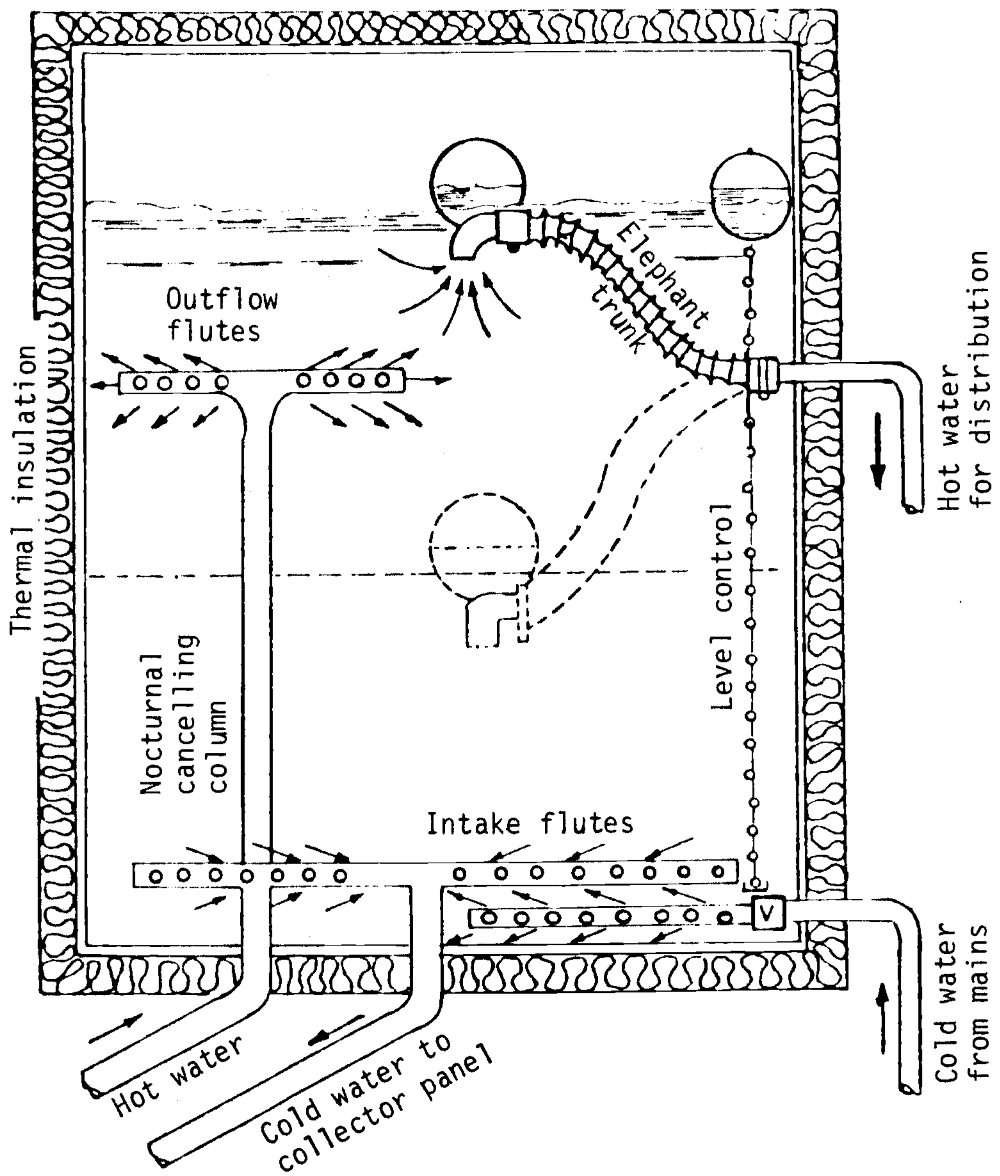


Fig. 5. The macrothermosiphon.

Research made it possible to build a macrothermosiphon capable of operating regardless of size. This unit had several design innovations:

- Collector feeding and discharge pipes were carefully balanced to keep hydraulic pressures constant in each unit within a few tenths of a millimetre.

- Graded diameter pipes maintained constant pressure drops along the whole manifold system.

- A standard insulation system minimized external losses.

- A leveling system made it possible to direct the bubbles produced during heating into the tank by gravity.

- Tank feeding and discharge systems operated through "flutes" to minimize the turbulence that produces thermodynamic inversions in the tanks.

- "An elephant trunk" feeding system made it possible to draw the hottest water from the tank for consumption, even during periods of water rationing, when the water level inside the tank dropped.

- A thermosiphon column cancelled at night the thermal inbalance within the thermosiphon branches, thus eliminating the major problem associated with this technology, i.e., nocturnal countercirculation, which renders energy storage useless.

Many more innovations were introduced, but these seven, as well as simulation techniques with prototypes -- sometimes very large ones (50 m^2) -- and the representation of collector performance as a mathematical expression of the second degree, show that the technology of large thermosiphons has been mastered.

Some technical characteristics of solar heaters

In Bogota (Niza VIII Project), more than 4000 m^2 of collector panels were installed and used as structural elements substituting for half of the conventional roof in the apartment building. For architectural reasons, 6 m^3 tanks made of reinforced concrete were used, with external insulation. Thermal inertia of concrete had an additional advantage: the heat capacity of the system increased by 29%.

For the design, daily average consumption of hot water for an apartment with a floor area of 100 m^2 was estimated at 340 L, almost double the actual consumption for this kind of housing unit; this represents savings of 17 kW.h/day.

The Colombian Experience

The utilization of solar energy in Colombia has some interesting characteristics:

- So far, Colombia has developed only 4% of its hydroelectric potential, estimated at 100000 MW.

- Most large cities are located in the higher tropics, with low environmental temperatures and moderate solar radiation.

- Residential electric rates are highly subsidized, which does not promote energy savings.

- The Colombian experience with solar energy has been successful, economically and socially, and service quality is satisfactory. Therefore, technological transfer to other developing countries where more favourable conditions exist will have a better chance of success.

Results of the economic evaluation

So far, solar-energy development in Colombia has been directed at homeowners in average and above-average socioeconomic strata. For a solar collector to be adopted in a new home, the savings in the electricity bill must compensate for the additional initial cost of this alternative, as compared with conventional electric heating.

It is estimated that the additional cost of a solar collector, per home, is $1100. This extra initial investment is amortized over 5 years, even if the electricity rates remain constant (in real terms). However, from a macroeconomic point of view, the situation is different, and the amortization period is much shorter.

Expansion costs of hydroelectric sources are ever-increasing because developments close to the larger cities, with the highest falls and the lowest transmission costs, have already been built. On the other hand, in Colombia, the electric rates are lower than the marginal expansion costs in this sector; the rates for average and above-average income groups only cover 64% of expansion costs. Thus, it is financially advantageous for the electricity supply companies to postpone investments. If we add to this the fact that Colombian currency is overvalued, we reach the conclusion that the investment for a solar collector should be amortized over 3 years.

An important factor in the continuity and success of the project has been the involvement of the Central Mortgage Bank (Banco Central Hipotecario) of Colombia.

Residential solar collector plan (1983-99)

Only 390000 homes will have solar technology by the end of the century if we use the following, pessimistic, assumptions for a residential solar collector plan:

- Collectors will be installed only in new homes;
- Only people in average and above-average income brackets will install collectors in their new homes; and
- Not more than 20% of new homes -- 5% of the total number of existing homes by the end of the century -- will have solar collectors.

The following simplified analysis can be made. In each home, substituted power will be 5.2 kW; assuming a diversity factor of 0.35 and energy transmission/distribution losses of 15%, each home would have required 2.14 kW at the generating plant (5.2 x 0.35/0.85).

In Colombia, each hydroelectric peak kilowatt costs about $840; adding some $210 for subtransmission and distribution and taking into account the 15% losses, the cost of 1 kW for the residential sector reaches $1235. Thus savings in fixed generation costs when using substituted power amount to $2643/home (2.14 x 1235). If the cost of electrical heaters and floor space used by the heater are added, the savings amount to $3836. The solar heater-storage system costs only $2100 and is, therefore, very attractive economically. In addition, the increasing real cost of electricity generation and the decreasing cost of solar heaters has not been considered.

Although it is not very ambitious, this program makes it possible to save some $1500 million in investments in the electric sector, a considerable sum for a developing country; and the consumers' savings are estimated at about $700 million. If lower-income groups also adopted the system, or if expected percentages were higher, savings would increase more than proportionally.

The program is under way in Colombia, and the results can be compared with those in any other developing country.