Harnessing of Renewable Energy Sources in ASEAN Countries

G.K. Nathan
Faculty of Engineering, National University of Singapore,
Singapore 0511

ABSTRACT

In this paper the prospect of exploiting renewable energy sources, such as solar insolation, wind energy, and biogas from animal wastes, as primary sources of energy, is investigated. The availability of these energy sources in their primary form is estimated and the necessity for more elaborate determination is highlighted. The statistical data presented and the energy estimates given bring out the desirability and advantages of using renewable energy sources to meet the energy needs of rural people in ASEAN countries.

Commercially available equipment and viable methods for conversion of renewable energy sources for rural applications are identified and their cost estimates are given. Based on the cost of various types of equipment and primary energy estimates a comparison is made between conversion cost into thermal and electrical energy from renewable energy sources. The investigation shows that a substantial part of the present energy needs of the rural community can be met by biogas production, and the importance of using renewable energy sources for applications they are best suited for is substantiated.

INTRODUCTION

Today, every country is confronted with a need to find suitable alternative energy sources to meet a part or whole of the energy requirements of its population, and to find methods to curtail the use of fossil fuel, whose spiralling cost is hampering development efforts, especially in developing countries. In many industrialized countries, national plans are being implemented to develop technology to exploit renewable energy sources, such as solar insolation, wind velocity, biomass etc. Unless developing countries make a similar effort to promote and develop appropriate technology, which is presently at a lower level, developing countries will be once again left behind to purchase the new technology at a high cost. Therefore, in less developed countries, developing suitable technology for renewable energy sources will be to their advantage in the future. The present technological era is built on the concept that ever increasing energy consumption is a prerequisite for technological progress which in turn increases the GNP per capita. This being so, the only way available to developing countries with a short supply of fossil fuel is to go in for renewable energy sources, which are inexhaustible and apparently available in abundance.

The development and application of renewable energy sources depends to a considerable extent on the population density, because the energy needs, social habits and purchasing power of people living in metropolitan, urban and rural areas are different from one another, especially in developing countries. In the ASEAN region there are more than 10,000 islands, and most people live in rural areas engaged in agriculture, fishing, forestry, etc. [1, 2] and do not have an adequate supply of energy, for their needs. In most cases, the cost of supplying centrally generated electric power would be prohibitive, because of the high cost of fossil fuel and the transmission network. Therefore, it is timely to consider non-conventional energy sources such as solar insolation, wind and biogas, which may be available nearby to provide potable water, water for lift irrigation, drying of crops, electrification of homes, etc. Such energy sources could definitely bring about immediate relief and a substantial improvement in the living standard of the rural population, provided the existing renewable energy technology could be readily adapted to the rural environment. This could only be affected through government participation and encouragement, as is the practice in industrialized countries.

The main objectives of this paper are to assess the availability of renewable energy sources, and to consider the status of the relevant technology and the cost of applying it. In the process, the shortcomings and advantages in the use of solar insolation, wind and biogas will be discussed, with regard to the useful contributions which have been made by ESCAP [3] and ACTI [4].

AVAILABILITY OF RENEWABLE ENERGY SOURCES

The first obstacle to the use of renewable energy sources is the lack of data, and consequently the primary task is to estimate or determine the total available energy at any particular place. In the case of solar insolation and wind it is necessary to know the annual, monthly and diurnal variation at a given place before using renewable energy. These variations are required to determine the size, storage capacity, capital cost, operating cost and the suitability of a particular renewable energy device. To estimate the available quantity of solar energy one could resort to data collected by the meteorological services of a country, but often most meteorological stations are established for purposes other than for determining the availability of energy. Nevertheless, some conclusions may be drawn as to the availability of solar insolation. With regard to wind energy, however, which is affected by trade winds, terrain and altitude, it is nearly impossible to assess the available energy without some preliminary studies. As for biomass, it is possible to make a fairly accurate estimate of its availability based on the number of people and animals in the area and the amount of land covered by vegetation.

Solar Insolation

In general, the most favourable parts of the world for solar insolation are found between latitudes 15° and 35° N and 15° and 35° S, where the best region has a monthly mean radiation of 20.9 MJ/m^2 per day (500 cal/cm^2 per day). The next most favourable part of the world is the equatorial region between 15° N and 15° S, where solar insolation is from 12.6 to 20.9 MJ/m^2 per day (300 to 500 cal/cm^2 per day) depending on the rainfall, cloud formation and humidity. In these latitudes there are about 2,500 hours of sunshine per year with few seasonal variations [3]. Most of the area covered by the countries in this region lies between latitudes 20°N and 20°S, and hence some estimate as to the availability of solar insolation may be made. However, the proportion of diffused and direct radiation depends on other factors, and this variable effects the selection of the most appropriate type of solar collector. Solar insolation data for Singapore [5] and Thailand [6] have been reported, which confirms the above estimated values.

Wind Energy

Whereas for solar insolation it is possible to make a generalized estimate of the available energy, such a generalisation is not feasible in the case of wind energy. This is because the wind velocity distribution is dependent on local factors. For the installation of large, high speed windmills it is a prerequisite to determine in detail the wind characteristics at the selected location. For low and medium speed windmills, however, available distribution may be used, preferably taking the precaution of making some measurement of windspeed before the selection of a site.

The number of stations recording diurnal wind data in the ASEAN countries is grossly inadequate. Presently there are 22 in Indonesia, 20 in Malaysia, 8 in the Philippines, 4 in Singapore and 5 in Thailand – whereas in Great Britain alone there are about 75 stations.

The potential wind power, P, in kilowatts is given by $P = 0.000613V^3$ per square metre, where V is the wind velocity in metres per second. Assuming an average power coefficient of 0.35, the available power is $P_a = 0.000215V^3$ kW/m^2. The total power available over the operating speed range of a windmill can only be determined when the speed and power duration curves, based on the diurnal variation of the wind speed over a period of time, are known. The major obstacle to the use of wind energy in the near future is the lack of information on wind data and technical services in the region. This problem can be overcome by preparing isovent maps and providing services to a prospective user for detailed measurement of wind data at a selected site. Such information and services are available in industrialised countries, and a similar service in developing countries together with some form of government support would encourage the use of wind energy.

From the data analysed for Singapore [8], it can be seen that the diurnal hourly mean velocity varies between 2 and 10 m/s at 10 m height, and similar results have been reported for other countries in the region [3]. Therefore, in general, the available wind energy in the region is suitable for low and medium speed windmills, which can be effectively used for small-scale generation of electricity and lift irrigation. But an extensive wind survey might lead to the development of other prospective sites in the region, and these might then be used for large-scale power generation which could be fed into the existing transmission network if required.

Biomass Energy

The majority of people in the region are primarily engaged in agriculture and animal husbandry (Table 1), and hence production of biogas by anaerobic digestion of biologically degradable

Table 1: Selected statistics on ASEAN countries for the year 1976 (refs. 1, 2)

DESCRIPTION	INDONESIA	MALAYSIA	PHILIPPINES	THAILAND	SINGAPORE
General					
Area of country km^2	1,904,569	329,744	300,000	542,373	602
Number of islands	3,000		7,000		39
Population in millions	128.400	11.900	52.517	41.87	2.25
Total employed in millions	39.692	3.295	14.518	13.815	0.870
Employed in agric., fishing & forestry %	62.85	47.92	53.51	62.56	2.26
GNP per capita (US$)	170	720	370	350	2,510
Livestock and poultry in millions					
Cattle	6.150	0.386	1.737	4.432	0.009
Buffaloes	2.243	0.213	2.725	5.947	–
Sheep	3.151	0.045	1.389	0.051	–
Goats	10.350	0.329	N.A.	0.030	–
Pigs	2.600	1.168	6.489	3.516	1.071
Chickens	93.881	40.000	45.671	47.805	13.198
Ducks	14.095	8.000	4.104	12,697	1.953
Annual energy data					
Production in coal equivalent x 10^{-9} kg	103.08	7.0	0.56	0.46	–
Consumption in coal equivalent x 10^{-9} kg	24.21	6.66	13.85	11.90	4.84
Total consumption TJ	784,514	215,813	448,805	385,612	156,839
Electricity generation TJ	12,041	19,291	44,489	28,474	15,032

organic matter has good prospects. However, extraction of this energy would depend on planning and organizational effort. Table 2 shows the biogas production data from highly biodegradable animal wastes, and Table 3 shows the potential biogas production in the ASEAN countries, in which the biogas production from the wastes of buffaloes, goats and ducks are assumed to be the same as from those of cattle, sheep and chicken respectively. It has been estimated that one cubic metre of biogas with 55% methane content will provide 20.502 MJ (calorific value = 1,000 Btu/ft^3) of heat energy [9]. This heat energy may be converted into electrical energy using a gas engine-generator set with an estimated overall efficiency of 20%. Electrical energy production from the available biogas is of the same order as the energy produced by conventional sources.

Table 2: Biogas production data of animal and human wastes (refs. 9, 10)

	AV. WT kg	kg/day		SOLIDS kg/day		BIOGAS FROM DRY SOLIDS	
		URINE	FAECES	DRY	VOLATILE	ft^3/lb	m^3/kg
Cattle	453.6	9.07	23.59	4.54	3.63	5	0.312
Sheep	31.8	0.68	1.36	0.23	0.18	8.0	0.549
Horses	385.6	3.63	16.33	3.18	2.49	N.A.	N.A.
Pigs	72.6	1.81	3.40	0.68	0.59	11.1	0.693
Chicken	1.59	–	0.14	0.04	0.03	4.3	0.268
Ducks	2.72	–	0.18	N.A.	N.A.	N.A.	N.A.
Turkey	6.80	–	0.23	N.A.	N.A.	N.A.	N.A.
Human	68.1	1.13	0.99	0.06	0.05	6	0.375

Table 3: Potential biogas production in ASEAN countries

ANIMAL	BIOGAS, (m^3/day) x 10^{-6}				
	INDONESIA	MALAYSIA	PHILIPPINES	THAILAND	SINGAPORE
Cattle	8.711	0.547	2.460	6.278	0.013
Buffaloes	3.177	0.302	3.859	8.424	N.A.
Sheep	0.398	0.006	0.175	0.006	N.A.
Goats	1.307	0.042	N.A.	0.004	N.A.
Pigs	1.225	0.550	3.056	1.657	0.505
Chickens	1.006	0.429	0.489	0.512	0.141
Ducks	0.151	0.086	0.044	0.136	0.021
Total	15.975	1.962	10.083	17.017	0.680
Thermal energy TJ/year	119,533	14,681	75,446	127,329	5,088
*Electrical energy TJ/year	23,907	2,936	15,089	25,466	1,018

*Assuming a conversion efficiency of 20%.

STATUS OF RENEWABLE ENERGY DEVICES

At present, devices for the conversion of alternative energy into electrical, mechanical and thermal energy are in different stages of development in various countries. Some are in the planning and design stages, some are being tested and are undergoing field investigation, and others are being commercially produced to order or in batches. The manufacture of renewable energy devices has yet to reach the mass production level to be competitive and cost effective with other contrivances using conventional energy sources. Nevertheless, where conventional energy sources are not easily accessible, or the quantity of energy required is very small and the extension of the national transmission network is expensive, renewable energy devices have a head start, provided some form of assistance is forthcoming to overcome the initial capital cost. This in turn can affect saving in foreign exchange required for fossil fuel for most of the countries in the region. With these comments in mind, the status of alternative energy devices that are being commercially produced or that are of proven viability, and that can be produced for use in rural areas, will now be considered and compared.

Solar Insolation Devices

Solar insolation is trapped in the form of thermal energy by collectors, which are mainly of three types: flat plate, evacuated tubes and concentrators. Today flat plate collectors may be used for space heating and cooling, the drying of crops, and for producing hot and distilled water. The temperature in a collector with a selective surface and double glazing can go up to about 90°C. If mechanical power is required to drive a generator or a pump, then a low pressure turbine using the Rankine cycle with a refrigerant as a working fluid is required. In this case, a higher operating temperature gives better efficiency, and hence advanced collectors such as an evacuated tube or concentrators are required, which results in high capital cost. The level of technology required for power generation is very high and more complex than that required for the other applications mentioned above. Sunlight can also be directly converted into electricity through the photovoltaic process using solar cells. This technology was earlier developed to supply energy for use in spacecraft, and in the future solar cells might make a significant contribution towards meeting man's electrical energy demand, especially in remote areas.

Table 4 gives the cost of solar devices in US dollars based on F.O.B. prices. Most of the devices are too costly to be purchased by any significant percentage of the population anywhere in the world. However, the technology is being tried out in public institutions with government assistance. Production of hot water for domestic use and space heating using solar insolation is gaining ground in certain parts of the world, especially in industrialized countries where government encouragement is being given in the form of tax rebate. Another area where it is economical is in the production of distilled water for storage batteries and rural hospitals, and in the arid zones as potable water.

It is interesting to note that there has been a tenfold drop in the price of solar cells, and the cost today is US$9,000 per peak kW. This price is expected to drop to US$300 per peak kW in 1986 [11]. If this happens then it is possible in the future that electricity produced from solar cells may be used for electrification of rural homes. The advantage of using solar cells is that electrical energy may be produced where it is needed, especially in remote areas where the demand is small and the cost of long distance transmission lines from a centralized power plant cannot be justified.

Another area where solar energy may be used economically is in the drying of crops and seafood using solar driers. For small-scale applications cabinet driers may be used, replacing the

Table 4: Commercially available solar devices

AVAILABLE DEVICES	REF NO	OUTPUT ENERGY	UNIT COST US$ F.O.B.
1. Solar	11	Electrical	9,000 per peak kw 300 per peak kW (1986)
2. Flat plate single glazing Inflow: air water	12	Heat	 100 to 125 per m^2 100 to 200 per m^2
3. Solar still (3.5 litre/m^2 per day)	12	Distilled water	16 to 32 per m^2
4. Solar hot water heater	12	Hot water	500 to 1,000 per unit
5. Solar pump (Rankine cycle) fractional unit	3	Water	22,000 per peak kW
6. Solar power (Rankine cycle) 1 to 3 kW unit	3	Electrical	20,000 per peak kW

age-old method of drying crops in the open, which causes a certain amount of loss and deterioration of valuable food. However, large-scale applications would depend on finding methods to reduce or absorb the cost of construction of flat plate collectors, which is a possibility if these collectors are designed as an integral part of the roof structure of a factory building.

Windmills for Pumping Water and Power Generation

The kinetic energy in the wind can be converted into mechanical energy using horizontal and vertical axis type windmills. In the past, before cheap power was available from prime movers using fossil fuel, windmills were widely used for pumping water and electrical power generation in industrialized countries, which greatly improved agricultural production and conditions of living. Again interest in windmills is being revived and they are being commercially produced in various countries. Figure 1 shows the plotting of the F.O.B. cost in US dollars of commercially available windmill-pump and windmill-generator sets, excluding the cost of the tower, against the rated power in kilowatts. The windmill-pump sets are mostly small in power rating and they have a mechanical arrangement to drive the reciprocating or diaphragm pumps. These are mainly used for irrigation and for supplying water for domestic use from tube wells. The water can be directly pumped for irrigation and for domestic use if it is stored in overhead water tanks which are small in size, but this adds to the cost. In the case of a windmill-generator set, energy has to be stored. It is normally stored as electrical energy in storage batteries which cost US¢8/Ah V. The capacity of storage batteries required would depend on the distribution pattern and diurnal variation of the wind, and the overall cost of installation would decrease if the capacity of the storage battery required is small. Another factor is the cost of the tower, which forms a high proportion of the total institallation cost of a windmill. The cost of the tower increases with its height and the rated power of the windmill rotor, as seen in Figure 1. The power available from the windmill is proportional to the cube of velocity; and if the mean velocity exceeds 4 m/s at any location, then the use of a windmill may be economical.

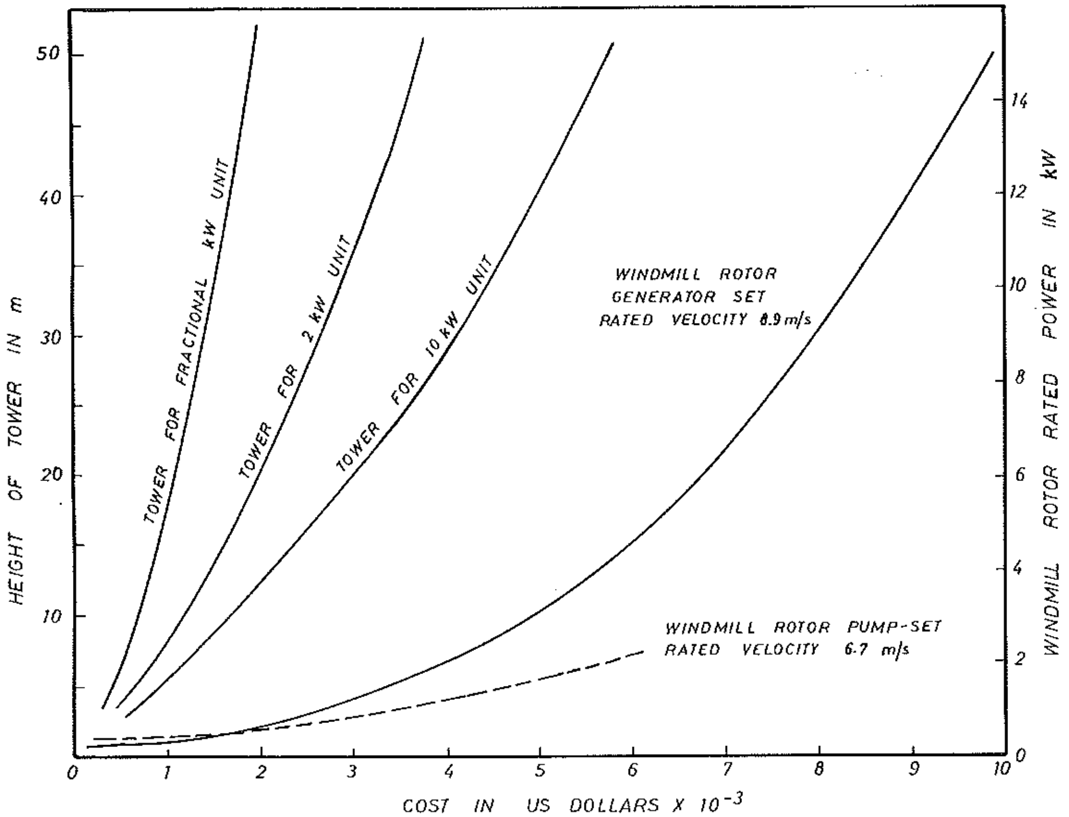

Fig. 1 Cost of windmill rotor for different power ratings, and cost of tower for different heights and power ratings of windmills. (1979, F.O.B. price).

Biogas – Thermal and Mechanical Energy

The biogas from a digester using animal wastes has about 55% methane, and it can be directly used in a burner to produce thermal energy. If mechanical power is required, then a modified petrol or kerosene engine can be run on methane gas, and the power produced can drive either a pump or a generator set. A modified petrol or kerosene generator set would cost about US$400/rated kW, and the cost of construction of the digester would vary between US$100-$200/m^3 capacity of gas at a standard temperature and pressure, depending on the design and the method of construction. Biogas digesters are being built and widely used in increasing numbers in India and China by organizations constituted by their respective governments.

COMPARISON OF TYPES OF ENERGY

Figure 2 shows the total energy consumption against GNP for Bangladesh and Sri Lanka at one extreme, France and the USA at the other extreme, and the ASEAN countries in the middle of the range. Also, the same figure shows the potential biogas energy production as a percentage of the total thermal energy consumption from conventional energy sources and the total percentage of population engaged in agriculture, forestry and fishing, etc. Both curves show a rise with decreasing GNP per capita. In countries which have an agriculturally based economy, a substantial

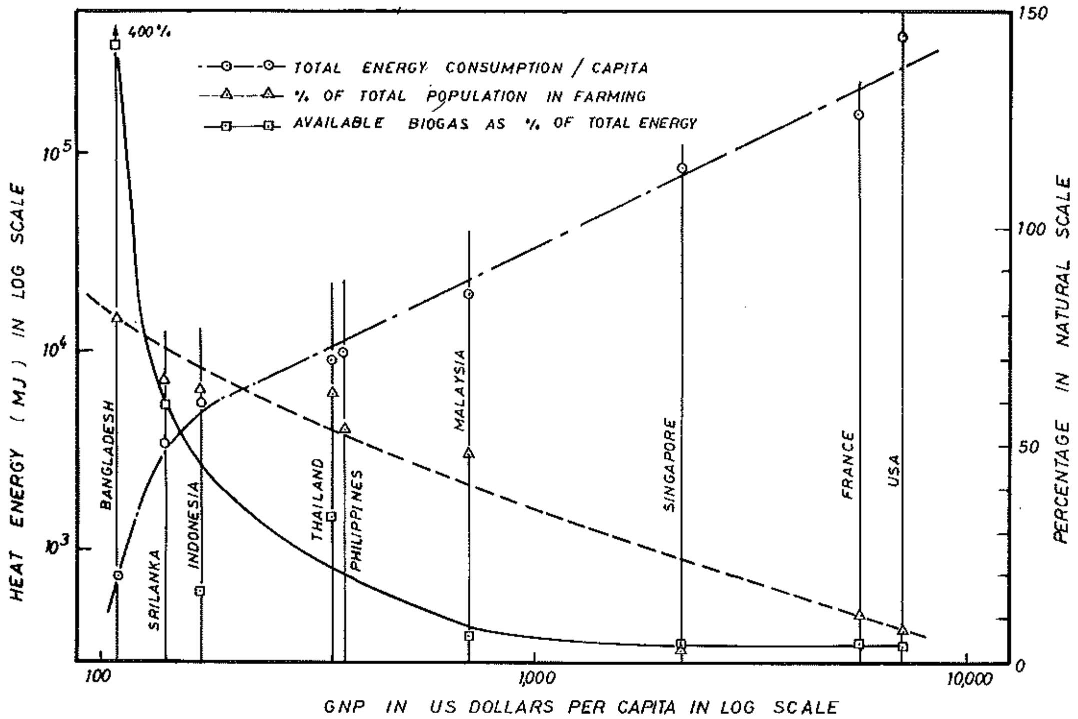

Fig. 2 Total energy consumption, biogas production and percentage population in rural areas versus GNP per capita for different countries (1976 statistics).

amount of the present electrical energy needs could be met by biogas production from animal wastes, as seen in Figure 2. Table 3 shows the potential electrical energy production from animal wastes in ASEAN countries, which would be further increased with the inclusion of agricultural wastes. Also the production of biogas has a valuable by-product – nitrogenous fertilizer.

A comparison of the cost of production of energy in the required form from different sources, such as solar insolation and wind and animal wastes, has its own drawbacks and difficulties. As units for a comparison of renewable energy sources, we have arbitrarily chosen 10 m^2 flat area for solar insolation, 20 m^2 vertical area for wind, and 1 head of cattle for biogas production. Assuming that the energy input is freely available and that there is an average efficiency for each conversion process, the energy output can be estimated. Based on the F.O.B. price in US dollars, the installation cost per MJ of energy production can be determined, and is given in Table 5. The estimated installation cost per MJ will be affected by the operating and replacement costs of equipment. Hence the comparison in Table 5 is intended to give an indication of the relative cost rather than the absolute cost, whereas for the selection of equipment this method of comparison gives a quantitative approach which is better than a qualitative approach.

This cost of production of energy would depend on the form in which it is required. If thermal energy is required, then by far the cheapest would be biogas, which costs US$5.50 per MJ, followed by a solar collector which costs US$23 per MJ. For power production, again biogas is the cheapest, except when the wind speed exceeds 8 m/s; but for windmills storage batteries are required, which would further increase the installation cost. However, today windmills are being used more widely than any other equipment for pumping water and for small-scale generation of

Table 5: Comparison of cost and production of alternative energy sources

SOURCE OF ENERGY	AVERAGE AVAILABLE ENERGY PER DAY			PRODUCTION OF ENERGY PER DAY			COST OF INSTALLATION IN US$	
	UNIT	FORM	MJ	EFF*	FORM	MJ	PER UNIT	PER MJ**
1. Solar insolation								
Collector	10 m^2	Heat	143.99	30	Heat	43.19	1,000	23
Solar cell (ref)	10 m^2	Photons	143.99	8	Electricity	11.52	7,500	651
Solar pump	10 m^2	Heat	143.99	5	Hydraulic	7.19	10,000	1390
2. Wind energy								
Windmill-power set	10 m^2	V = 4m/s	33.91	20	Electricity	6.77	3,000	443
		V = 6m/s	114.34	20	Electricity	22.89	3,000	131
		V = 8m/s	271.17	20	Electricity	54.28	3,000	55
		V = 10m/s	529.59	20	Electricity	105.90	3,000	28
Windmill-pump set	10 m^2	V = 4m/s	33.91	15	Hydraulic	5.29	2,000	378
		V = 6m/s	114.39	15	Hydraulic	17.17	2,000	116
		V = 8m/s	271.17	15	Hydraulic	40.71	2,000	49
		V = 10m/s	529.59	15	Hydraulic	79.45	2,000	25
3. Biogas								
Burner	1 cattle	Methane	1.5m^3	–	Heat	30.74	170	5.5
Gas engine-generator	1 cattle	Methane	1.5m^3	20	Electricity	5.79	400	69

* Average efficiency in percentage for conversion from available sources of energy to required form.
**Lower installation cost (F.O.B., 1979) for production of 1 MJ per day based on available technology and commercial equipment.

power in remote areas. Therefore, in this region a strong effort should be made to tap wind energy and biogas production. Solar cells can be used for small applications, such as telephones, remote measuring stations, etc. If the price of solar cells falls by 30 times the present price in 1986, as predicted, then solar cells will be best suited for power generation in sparsely populated areas.

The available solar insolation and wind energy are subject to diurnal and seasonal variations, and wind energy is also affected by terrain. Figure 3 shows the monthly wind energy for Singapore International Airport and for an offshore island, and also the average monthly solar insolation for the former. Figure 4 shows the diurnal variations of wind energy and solar insolation on which wind energy corresponding to two average wind speeds are superimposed. This shows the variability of solar insolation and wind energy with time and wind speed. In the ASEAN region it is known that solar insolation is abundantly available, and for most of the solar applications referred to here an approximate estimate of solar insolation over a larger area with fewer measurements is sufficient; but the availability of wind energy can only be assessed with extensive measurements, which is costly and poses a bigger problem. If the energy available from biogas, which can be easily estimated, is superimposed on these figures it would appear as a horizontal line, indicating that the supply is independent of time because biogas is continuously available from a digester. Therefore, when planning for the future use of renewable energy sources, if a combination of primary sources is considered, then it will ensure the reliability of supply.

To use renewable energy sources optimally, they have to be used directly in the form in which they are available and for the purposes which they are best suited for. Therefore, in the future, whenever possible, energy planning and management should be such that different forms of energy are used directly rather than depending on electricity as a primary source for every appli-

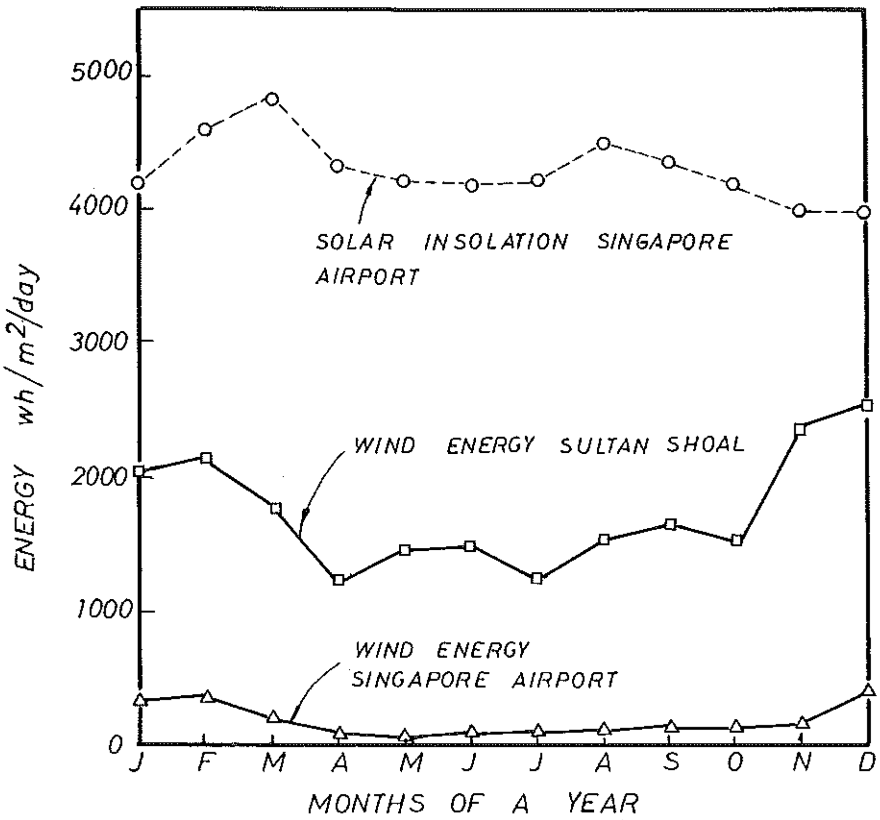

Fig. 3 Monthly mean solar insolation and wind energy in Singapore.

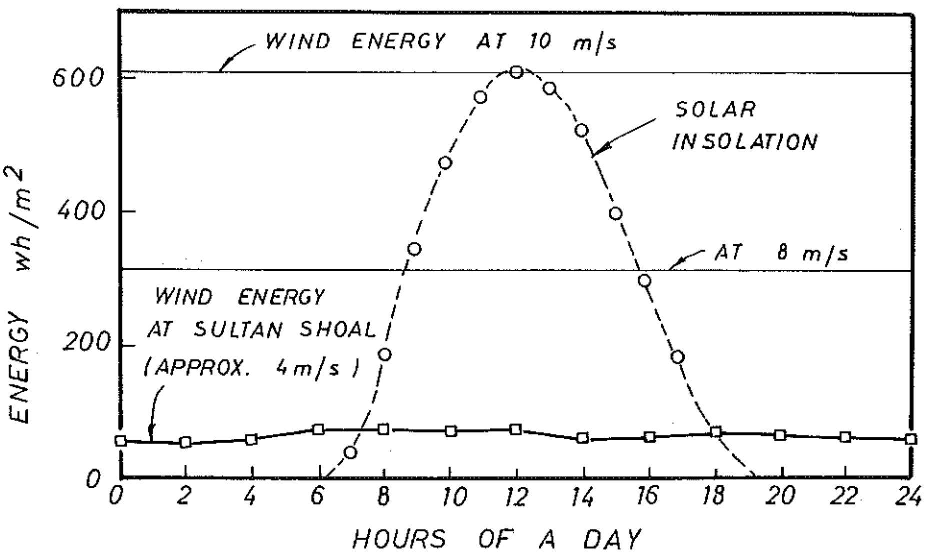

Fig. 4 Diurnal solar insolation and wind energy in Singapore, and wind energy at different wind speeds.

cation. Figure 5 shows a line diagram to achieve such an objective. An approach along these lines, which is being attempted under U.N. sponsorship in a few villages around the world, may have the key to the energy problems of tomorrow in rural areas. The integrated approach has the advantage that it can overcome the seasonal variation effect, which in a way is hampering the progress towards the use of renewable energy sources.

Another drawback is the high cost of renewable energy sources equipment. One reason for this is that equipment is mainly produced either to order or in batches, which means that it does not have the same advantage in price as mass-produced equipment. Therefore, if it is produced locally making use of inexpensive labour its price can be reduced. In some cases the equipment can be fabricated locally with mass-produced components from industrialized countries. There will be an incentive for such a programme provided there is support from and participation by the government to popularise the use of renewable energy sources so as to make a definite impact on the energy scene.

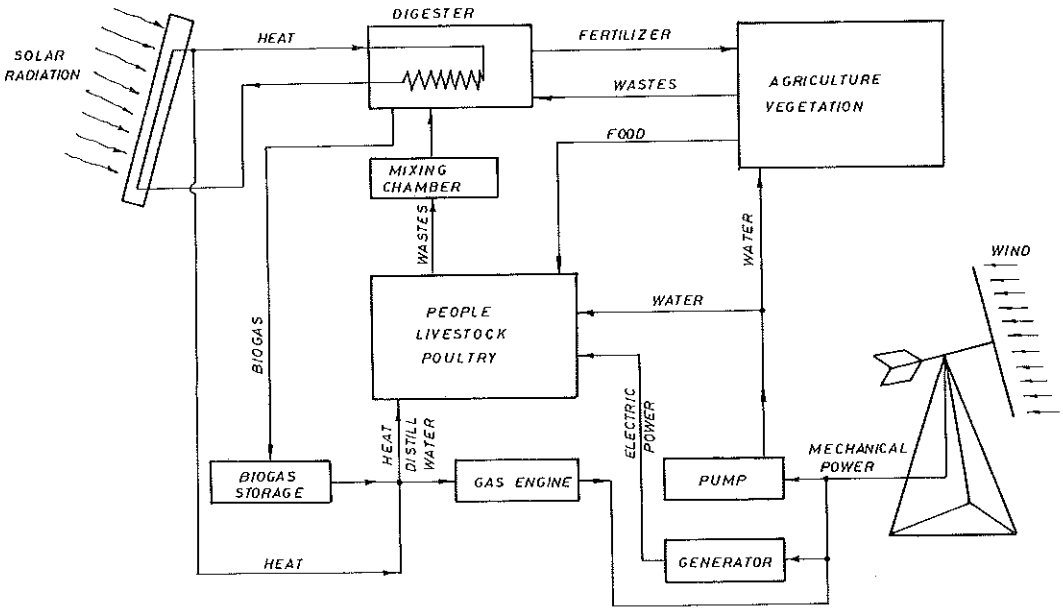

Fig. 5 Energy flow chart for probable combined application of renewable energy sources in rural areas.

CONCLUSIONS

1. The investigation shows that in countries which have an agriculturally based economy the potential biogas energy production from animal wastes is of the same order as the total energy consumed, and the inclusion of agricultural wastes would further increase potential biogas energy production.

2. In ASEAN countries the majority of the population lives in rural areas engaged in agriculture, forestry and fishing, where biogas production is possible. This form of energy can be

immediately used with existing technology, and an appreciable impact could be made on the energy scene.

3. The mechanical power available per unit area from wind energy, which is a function of wind speed, is much higher than that from solar insolation. Efforts should be directed towards conducting an extensive survey to evaluate and assess the available wind energy in this region.

4. The comparison of different forms of energy for the production of thermal and mechanical energy shows that biogas energy has an edge over the others. Solar collectors are also suitable for production of thermal energy, especially for low-grade heat required for drying of crops, distilled water and hot water.

5. If the average wind speed is over 8 m/s, it is the cheapest method of producing electrical power, and proven technology is available for immediate application. However, for pumping water, a wind speed as low as 4 m/s may be used.

6. Solar cells for power generation will be the cheapest compared to other alternative resources provided that the cost of solar cells drops to the predicted value of US$300 per peak kW in 1986.

7. If attention is paid to developing integrated alternative energy systems, then dependability on renewable energy may be increased. In the case of rural populations, if the proposed system is such that a greater part of the available energy is utilized for increasing production, rather than just for domestic use, then the system would give a better return on the capital and be more attractive.

REFERENCES

1. *United Nations Statistical Year Book 1976* (1977), United Nations, New York.
2. *The Europa Year Book 1978 – A World Survey* (1978), Europa Publications Ltd., London.
3. ESCAP – Economic and Social Commission for Asia and the Pacific (1976), *Proceedings of the Meeting of the Expert Working Group on the Use of Solar and Wind Energy,* United Nations, New York.
4. ACTI – Advisory Committee on Technology Innovation (1976), *Energy for Rural Development: Renewable Resources and Alternative Technologies for Developing Countries,* National Academy of Sciences, Washington D.C.
5. TAN, K.J. and T.N. GOH, (1977), Solar Insolation in an Equational Region (Singapore), *Solar Energy,* Vol. 19, pp. 101-103.
6. EXELL, R.H.B. (1976), The Solar Radiation Climate of Thailand, *Solar Energy,* Vol. 19, pp. 349-354.
7. WMO – World Meteorological Organization (1978), *Weather Reporting,* Vol. A, WMO/OMM No. 9, Geneva.
8. NATHAN, G.K. et. al. (1976), A Study on the Use of Windmills in Singapore, *International Symposium of Wind Energy Systems,* BHRA, Cambridge, paper A5, pp. 75-87.
9. ACTI – Advisory Committee on Technology Innovation (1977), *Methane Generation from Human, Animal and Agricultural Wastes,* National Academy of Sciences, Washington D.C.

10. FRY, J. (1975), *Methane Power Plants for Rural Energy Independence,* Chapel River Press, Hampshire, England.

11. *Mechanical Engineering* (1979), Vol. 101, No. 7, pp. 20-21.

12. *Sun Catalog* (1979), Solar Usage Now, Inc., Box 302, Bascum, Ohio 44809.