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Technical and Socio-Economic Aspects of Hybrid Renewable Energy Sources: A Step-by-Step Approach

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Abstract

In this paper a step-by-step approach is presented for the adoption of technologies designed to exploit hybrid renewable (solar, wind, biomass and small hydro) energy Systems at the rural level. It is centered around the establishment of rural energy centers to improve the basic living environment. In due course, the role of these centers is to be expanded to encompass agricultural, domestic, transport and small-scale industrial activities. The technical, economic and socio-economic aspects of the step-by-step introduction of renewable energy systems in rural areas in developing countries are discussed.

The acute energy needs and the unavailability of commercial fuels in the rural areas offer a rewarding opportunity for the utilization of locally available renewable energy sources. Small-scale decentralized hybrid system concepts for harnessing renewable energy sources are discussed.

Keywords: Renewable energy Sources, Technical & Social-economic Aspects, Hybrid Renewable Energy System Aspects

INTRODUCTION AND LITERATURE REVIEW

The decade of the 1970's will go down in history as the one that brought into focus the limited and geological nature of the non-renewable energy sources of the world and the need to start the process of transferring the dependence, at least partly, onto renewable energy sources. For the nearly one billion people living in scattered rural areas of developing countries in the continents of Asia, Africa and South America, the consequences of the massive changes in the global energy scene have been devasting. They find themselves trapped in a cruel race between demography and development.

Resolution of these global problems will be a very slow and painful process. Initial efforts must be concentrated in rural areas to improve the basic living environment and agricultural productivity, which eventually will mitigate the exodus to urban slums-the most regressive of the entire happening in the developing countries of the world. This initial effort will require a phenomenal increase in the use of renewable energy in the rural area [1]. The developing countries of the world, especially the ones that are resource-poor and population-rich, are confronted with a multitude of complex problems involving population growth, economics, energy and development. Unfortunately, all these problems are closely interrelated and they have been seriously aggravated by the unprecedented increases in the oil prices of the recent past [2-6]. All reasonable solutions to alleviate these problems involve sharp increases both in the moment of energy consumed and in the efficiency of their use. This paper is concerned with the role of hybrid renewable energy sources in meeting this challenge [7-8].

The urban and suburban areas of developing countries will continue to depend on “commercial” fuels (coal, oil, natural gas and nuclear) and the total amount of such fuels consumed will steadily increase well into the twenty-first (21) century. However, the rural and remote areas, which depend almost entirely on “non-commercial” or “traditional” fuels (fire woods, agricultural wastes, and animal wastes) will be very adversely affected if nothing is done to reverse the present trend of highly inefficient usage and mismanagement of natural resources such as forests and agricultural land. The net result will be mass migration (which is already occurring in many parts of the world) into over crowded cities, leading to all round unpleasant conditions for everywhere in the future.

This paper presents an overview of the hybrid renewable energy technologies of interest for use in developing countries and discusses rural energy needs and renewable technology options available to meet the requirements. Hybrid Renewable Energy System concepts and their advantages are discussed along with the economic and socio-economic implications of introducing renewable energy systems in rural areas. Increased emphasis on rural development will require a phenomenal increase in the use of energy in some form or other in rural areas. A distinct departure must be made from the age old techniques of exclusively using manual and animal labour, animal wastes are firewood (and charcoal) as the main sources of energy. Past experiences has shown [9] that such methods are highly regressive in human as well as environmental terms [3]. Most of the developing countries are poor in conventional fossil fuel resources and have to import them at the expense of their meager foreign exchange reserves. More importantly, they cannot afford to base the hopes and aspirations of their teeming millions on depletable fossil fuels lying under some foreign soil. Therefore, instead of trying to follow the "first world" countries and taking the path of increasing dependence on depletable fossil fuel, it has been suggest [9] that they develop, encourage and plan their development programs on increased use of renewable energy sources in its various manifestations. This paper also discusses a step-by-step approach for the adoption of technologies designed to exploit hybrid renewable energy sources at the rural level. The discussion in this paper is confined to solar radiation and solar heat, wind energy, biomass, and falling water.

RENEWABLE ENERGY SOURCES

The renewable energy sources, which are present in these day in small-scale in the rural areas of developing countries, are in the form of solar energy (SE) – i) solar radiation, and ii) solar heat (PV system), wind energy (WE), biomass (BE) and small hydropower (SHP) (falling water). The term biomass is used to include wood, agricultural wastes, and animal and human wastes. In addition, the muscle power of humans and animals is also available in the rural areas. Geothermal, Tidal, Ocean-thermal, and Wave energies are also renewable, but they are very site-specific.

Estimation of rural energy consumption and needs are varying widely [10-14]. While some of this is due to their country-specific and site-specific nature, the primary reasons for the discrepancies are:

i) The assumptions made regarding the efficiency of use, and

ii) The inclusion or exclusion of human labour, animal work, transportation needs, irrigation needs, and the energy required for small-scale rural industries.

In a reasonable manner, consistent pictures can be obtained by considering only the useful (output) energy (excluding the efficiency factor, which depends on the fuel and the mode of use) and the energy needs of small rural communities fall into three categories:

1) Energy to improve the basic living environment;

2) Energy to improve agricultural productivity; and

3) Energy to establish and sustain small-scale industries.

While both renewable and non-renewable energy sources can be used to satisfy these needs, the focus in this paper is on renewable energy sources.

A step-by-step, comprehensives listing of various needs and the renewable energy technology options are given under the three categories listed above given next section.

Rural Energy Needs and Renewable Energy Technologies

Energy to Improve the Basic Living Environment

Category	Needs/Tasks	Options	Remarks
Domestic Environment	*Cooking*	Supply of biogas Solar cookers Firewood/Dung/Agricultural Residue Vegetable oil Electricity from the village Energy Center (VEC); Biogas-IC-Engine-generator Animal fat	Most appropriate Difficult to adopt to local culture Environmentally recessive Needed for human intake & other uses Wasteful of energy Neither suitable nor available in sufficient quantities.
	Domestic & potable water supply	Wind-driven mechanical water pumps Integrated wind-driven permanent magnet generator (PMG)-Motor-Pump Combination Integrated photovoltaic-motor-pump sets Biogas fueled Engine Pump Sets Hydraulic ram	Economic; need good wind regime. Convenient; water source and wind mill need not be at the same location. Low maintenance; convenient, expensive at present. Not readily available; can be developed Need low head to start with; commercially

		Electricity pump sets	available at present. Convenient; need electricity supply
	Lighting *Cold storage of perishables*	Electricity from VEC Biogas Lamps Electricity from VEC Solar refrigeration Unit	Convenient; high energy efficiency possible with fluorescent lamps. May not be very convenient Expensive; very low priority in poor households. Does not appear viable for single-family households.
Community Environment	*Street lighting* *Educational devices* *Emergency and communications equipment* *Water sanitation* *Community cold storage* *How water for schools and dispensaries* *Space heating and/or coolingfor community biogas*	Electricity from the VEC Biogas lamps Electricity from the VEC Electricity from VEC; supplied from the storage batteries Electricity or gravity & chemical. Electricity from the VEC Solar refrigeration unit Solar flat-plate hot water heaters Solar space heating and cooling systems.	Convenient Not very convenient Located in a suitable hall in the VEC Located in a suitable room in the VEC; reliability important Located near the water storage and pumping station Located in the energy center and managed by an attendant Can be located in or near the VEC; expensive at present Viable at present Though available at present, they are very expensive and may not be suitable for rural use at present

Energy to Improve Agricultural Productivity

Category	**Needs/Tasks**	**Options**	**Remarks**
Pre-harvest Activities	*Irrigation Water Supply*	Wind-driven mechanical water pumps Integrated wind-driven-PMG-Motor-pumps Integrated photovoltaic- motor-pump sets Biogas fueled engine-pump sets Hydraulic ram Electric motor-pump sets	Economic; need good wind regime Convenient; wind mill can be located away from the water source Low maintenance; expensive Can be developed easily in suitable sizes Need low head flowing water; commercially available Convenient; need electricity supply
	Land preparation	Small tractors and gad gets run by liquid and gaseous fuels obtained from biomass	Need development and fabrication

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	Fertilizer	Sludge material obtained from biogas plants Using wind energy, air and water to synthesize nitrogenous fertilizers	Viable at present System must be large to be economic; need prototype development; good wind regime needed
Harvesting	*Mechanical power*	Small harvesting machinery running on liquid and gaseous fuels obtained from biomass	Need further development
Post-harvest Activities	*Motive power for transport*	Small vehicles running on liquid and gaseous fuels obtained from biomass	Need further development
	Processing the harvest	Small gadgets running on electricity from the VEC or on liquid and gaseous fuels obtained from biomass	Need further development
	Grain drying and storage cold storage of perishables	Solar grain driers or driers cum storage units Electricity from VEC Solar refrigeration unit	Viable at present May not stand long supply interruptions Can use the heat rejected by a concentrating solar thermal plant.

Energy to Establish and Sustain Small-Scale Industries

Category	Needs/Tasks	Options	Remarks
Thermal Energy	*Low grade (less than 150ºC)*	Flat-plate collectors	Viable at presents
	Medium grade (150ºC to 300ºC)	Line-focusing parabolic collectors	Viable, depending on the use
	High grade (above 300ºC)	Point focusing dish collectors Wind mill-mechanical friction device with suitable thermal energy storage	Viable, depending on the use Cumbersome; considerable maintenance required; need good wind regime
	General	Wind-Electric Conversion System (WECS) dumping energy into an electric resistance heater with suitable thermal energy storage Burning biogas Burning biomass/ agricultural residue Wind mill Waterwheel Solar thermal plant	Low maintenance; need good wind regime. Wasteful; better uses exist Environmentally recessive Intermittent; need good wind regime Need storage reservoir, or continuous water flow; very site specific Need concentrators to improve the overall efficiency to decent values. Closed cycles may be expensive.
Mechanical energy	*Rotating shaft*	Photovoltaic-electric motor combination Biogas fueled engine Electric motor	Expensive; problem of cloud cover and need for electric energy storage. Biogas availability above beyond the domestic needs. Need to generate electrical energy by one or more of the many means available; expense involved in the storage of electrical energy (if needed).

RENEWABLE ENERGY TECHNOLOGIES

Renewed worldwide interest in the harnessing and utilization of renewable energy sources is primarily attributable to:

i. Increasing environmental concerns over issues such as air quality, global warming, and acid rain;

ii. The steady progress achieved in renewable energy technologies; and

iii. The realizations of the enormous need to energize the remote rural areas of developing countries where the only locally available energy resources are renewable.

Technologies to harness renewable energy sources fall under two broad categories; "mature" and "emerging". Biomass-fueled power plants, biomass digesters, and hydroelectric systems come under the "mature" category. Wind-electric conversion systems (WECS), photovoltaic system (PV), solar-thermal-electric conversion (STEC), and the various schemes proposed to harness ocean energy (waves and thermal gradients) belong to the "emerging" category.

OVERVIEW OF THE ASPECTS

All renewable energy resources track back to the Sun. They are replenished seasonally by nature. Solar radiation and heat, wind energy, biomass and small hydro (falling water) are some of the resources considered for utilization in developing countries. They are free, plentiful and are fairly evenly distributed in the world, but require capital-intensive hardware for collection and conversion to useful forms. Developing countries are well endowed with one or more of these resources and, in many instances; they can be utilized with the intermediate technology and human resources available in such countries.

A realistic evaluation of the technologies proposed for rural level use in developing countries results in the list given below:

(1) Solar Radiation (SR)

a) Photovoltaic-powered water pumping systems for domestic use and for micro irrigation systems.

b) Direct generation of electricity using photovoltaic arrays for storage and later use.

(2) Solar Heat (SH)

a) Flat-plate collectors for supplying hot water for hospitals, schools, etc. [15].

b) Linear and point-focusing collectors with suitable energy conversion devices to generate electrical, mechanical, and / or thermal energy.

c) Solar stills for potable water.

d) Solar crop driers and other agricultural applications.

e) Solar ponds for thermal collection, energy storage and reconversion (i) Non converting solar ponds [16] and (ii) shallow solar ponds [17].

f) Space heating and cooling systems.

g) Sun/earth tempered buildings.

(3) Wind Energy (WE)

a) Wind – driven water pumps with mechanical or electrical transmission.

b) Wind – electric conversion systems (WECS) for generating of electricity [18].

(4) Small Hydropower (SHP) (or Falling Water)

a) Micro hydro systems (1 kW to 1 MW) for generating of electricity.

b) Mini hydro systems

c) Pico hydro systems

d) Water wheels for mechanical shaft power

e) Hydraulic ram for pumping water

f) Isothermal hydraulic air compression and the subsequent use of the compressed air for variety of applications.

(5) Biomass Energy (BE)

a) Anaerobic fermentation of human, animal, and agricultural wastes to obtain biogas for use in several ways and its subsequent use in internal combustion engines and also for direct use as fuel [19]

b) Fermentation of biomass to produce alcohols.

c) Pyrolysis or aqueous pyrolysis of biomass to produce liquid and/or gases fuels.

d) Direct use of biomass such as wood for production of thermal and other forms of energy.

e) Unique approaches to biomass utilization such as aquaculture wastewater treatment and energy forms.

TECHNICAL ASPECTS

A Step-by-Step Approach [20]

In rural areas where conventional fuels and utility grid supply are not available at present or will not be a major factor in the foreseeable future, it is proposed that renewable energy systems be introduced in a step-by-step fashion in three steps (or phases) as outlined below:

Step-I: Providing energy to improve basic living environment

(a) Water pumping and water supply.

(b) Potable water supply and purification.

(c) Educational and communication devices.

(d) Household electricity.

Step-II: Providing energy to improve agricultural productivity

(a) Irrigation water supply.

(b) Improved crop drying and storage facilities.

(c) Controlled environment agriculture.

(d) Cold storage of perishables.

(e) Minor agriculture processing machinery.

(f) Fertilizer productivity.

Step-III: Providing energy for long range, industrial and community level uses

(a) Heating and cooling of buildings such as schools and hospitals.

(b) Hot water supply for schools, hospitals and community buildings.

(c) Small-scale industries.

Applications

- The application proposed in **Step-I** will have a duct beneficial impaction the living environment at the rural level. They should provide the basic amenities of living and start the process of building up hope and confidence that the cumulative impact of the proper use of even small amounts of intermittently available energy in rural areas can be considerable. Having started this process, the hopes should be reinforced by the build-up of "rural agro-industrial structures".
- The applications proposed in **Step-II** are intended to accomplish this objective. Implementation of Step-II will increase agriculture productivity and generate the necessary "work places" in rural areas and the capital necessary to acquire, maintain and sustain hardware to harness renewable energy sources.

Geographical location of the country and the village and local conditions will eventually determine the application priorities for the most effective use of energy.

ENERGY REQUIREMENTS

Step-I: Rural energy requirements depend on many factors and no generalizations are possible [21]. The estimates given here should be taken as a guide to compute minimum energy requirements for the applications listed under Step-I.

Per Capita Energy (PCE) in kWh per day – Step-I:

- Domestic water pumping and water supply (0.12 m^3/person/day; total head 35 m; overall efficiency 23%) = 0.05 kWh/day.
- Water sanitation = 0.04 kWh/day

  Potable water supply and purification (0.01 m^3/person/day; rest same as domestic water supply) = 0.006 kWh/day.
- Educational and communication devices = 0.012 kWh/day.
- Street Lighting (15 lamps of 100 W each for 4 hr/day; distribution efficiency 70%; 250 people) = 0.034 kWh/day.
- Household electricity use;

  Lighting (120 W for 4 hr a day per family of 5; distribution efficiency 70%) = 0.138 kWh/day.

  Cooking (1.0 kW for 2.5 hr a day per family of 5; distribution efficiency 70%) = 0.72 kWh/day.

TOTAL 1.0 kWh/day

Step-II and Step-III:

Much depends on the geography, local circumstances and the number and nature of work places to be created in any particular village. Techniques are available to estimate the energy requirements once the necessary data is assembled.

Proposed Systems

Step-I: It is proposed to establish an energy center in each village with the objective of providing the basic needs of human existence. Most of the energy related activities will be controlled from this village energy center. The center will have an internal combustion engine (capable of operating on biogas), driven electrical generator and distribution lines emanate from this point to supply all the houses. Wind mill

farms located in nearby areas pump electrical energy into this small power system and augment its total generation capacity whenever wind is blowing. The person in charge of the center should be trained to make use of the energy in the wind when available by properly scheduling the loads in the wind when available by properly scheduling the loads. A small number of storage batteries in the center are used to supply emergency and communications equipment. The center will have facilities for people to radio or which education television. A schematic of the electrical system is shown in Figure 1.

When supply system is shown in Figure 2. It possible, wind-driven mechanical water pumps can be used to pump water from the source to the purification and pumping station.

Otherwise, electric motor driven pumps is employed. If the quality of available water is adequate, with some purification, the same water supply system can provide both domestic and potable water. We not, a separate drinking water supply system should be established. Control of water supply is also located in the energy center. The residents will get their water supply from community taps located at several points in the village.

Not shown in Figure 1 and 2 is a biogas plant and sufficient gas storage to provide energy (directly, if necessary, or through the internal combustion engine in the energy center) during calm spells in the wind regime.

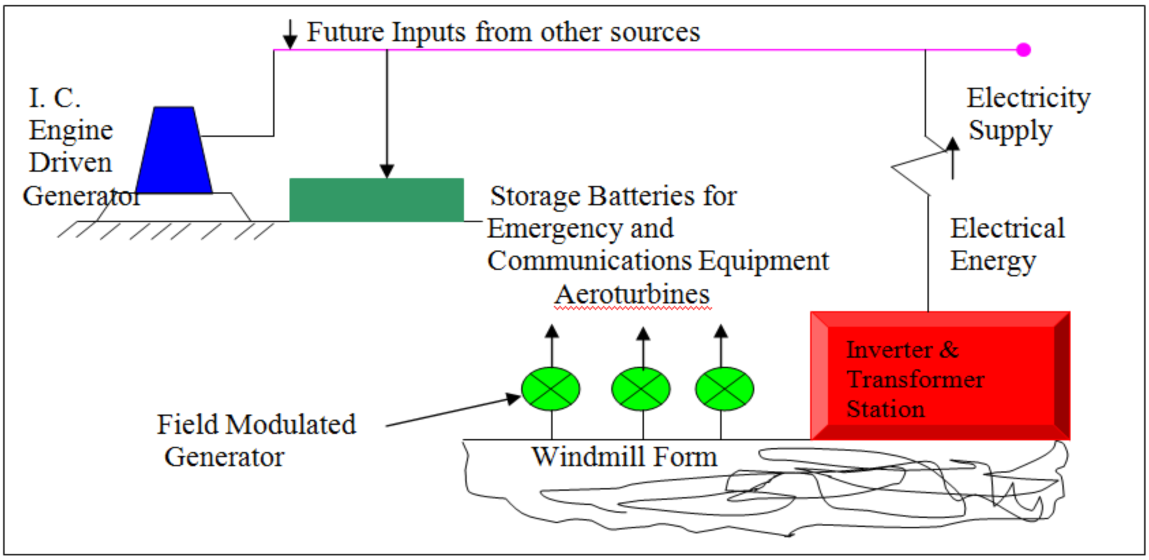


Figure 1: Schematic of the Electrical Station

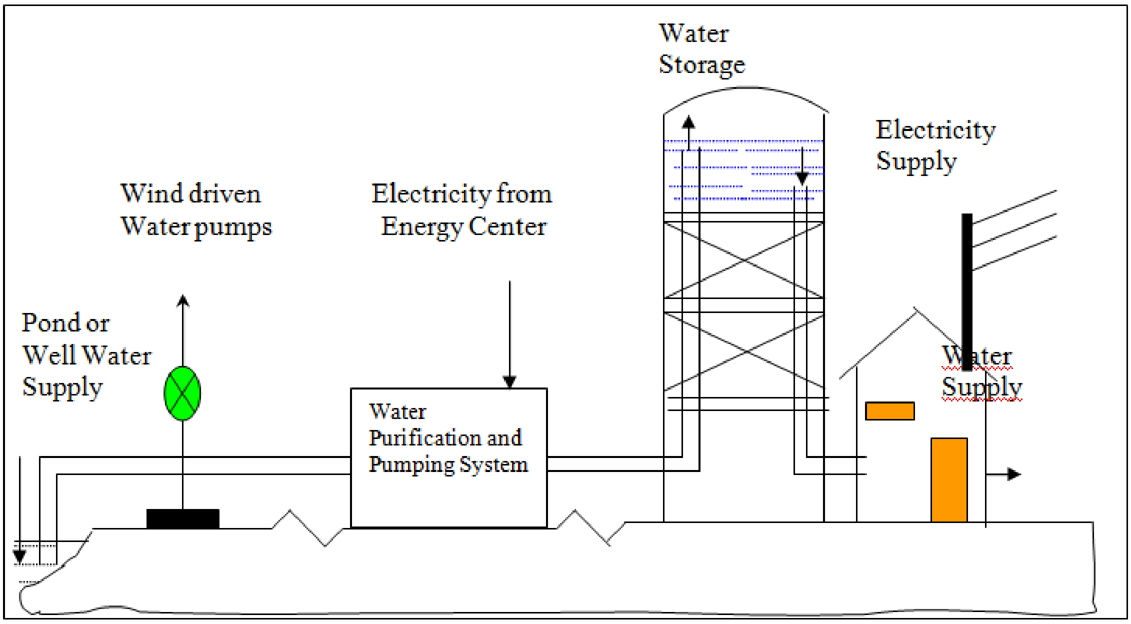


Figure 2: Water Supply System and Energy Center

Estimations of the sizes of different components required are given below:

Assumptions

1) Village has 50 families, 5 members each

2) Only one day of water storage will be provided

3) Energy center operator can schedule the loads to cut the peak demand by two-third (2/3), if necessary.

4) Biogas storage will be provided to take care of two days of calm in wind.

5) Overall efficiency of IC engineer-driven generator unit is 30%.

Size of water storage tank (4.5 m dia and 2 m deep) = 31.8 m^3. Size of the IC engine generator unit = 20 kW, Rated generating capacity of the windmill farm = 30 kW, Amount of biogas storage needed (20 kW for 8 hr) = 105 m^3. Assuming a rated speed of 9 m/s, total swept area required for aero turbines is 220 m^2 or 5 units of 7.5 m dia. each. The aero turbines can drive variable-speed constant-frequency field modulated generator system [22] and their constant-frequency output can be directly pumped into existing distributions lines. When wind speed reaches the designed cut-in value, the operator in the energy center will start the I.C. engine-generator unit (if it is not already running) to provide the necessary excitation to the wind-driven generators and simultaneously switch on proper loads.

In developing countries, it is common to find clusters of 4 or 5 villages, for away from other such clusters and towns. Often such groups of villages are not electrified because of the economics involved in supplying a small load by a long distribution line. For such cases, one village in the cluster can be selected to locate the energy center for supplying electricity and a distribution line can be installed to connect all the villages. Wind mill farms located in nearby areas can then pump electrical energy into this system as discussed earlier. A schematic of this approach is illustrated in Figure 4.

Under certain special circumstances, a combination of solar cell arrays and secondary batteries can be used to provide [23] energy to operate educational television sets in very remote rural areas. A schematic of this arrangement is shown in Figure 2 (a) below. At present, world production of solar cells for terrestrial applications is too small to advocate such systems on a large-scale. As demand grows, this situation is bound to change. Economics competitiveness of this approach is discussed in the next section.

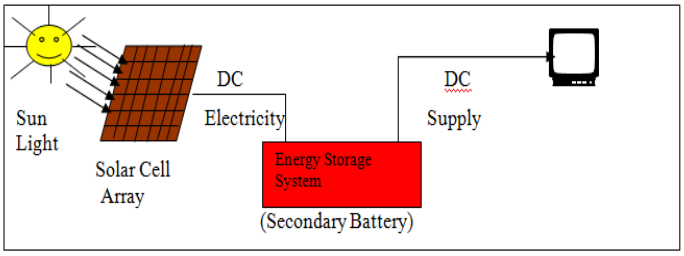


Figure 2(a): System Using Solar Cell Arrays and Energy Storage

ECONOMICAL ASPECTS

Any discussion of the economics of renewable energy sources must include the following factors:

(i) Social cost vs. individual cost, and

(ii) The form in which energy is used at the customer's end and the alternatives being compared.

In addition, if the renewable energy system is intended to supply the basic energy needs of remote rural communities in developing countries, the eventual direct and indirect costs of not making an effort to improve their environment should also be considered. However, this is complicated by the implied demographic, social, and political overtones and therefore the discussion that follows will concentrated only on the two factors listed above.

Renewable energy systems are, in general, characterized by high capital costs, low operation and maintenance (O&M) costs, and zero fuels costs. The only exception is the class of systems utilizing purchased biomass. At a minimum, the tangible value of the output of a renewable energy system should meet all financial obligations including loan amortization and O&M costs. Often, there are accumulated benefits and costs from the overall societal point of few, which includes both tangible and intangible benefits, such as recreation, flood control, fisheries, etc., and comparable costs such as waste production and management, adverse health effects, etc. If social costs outweigh social benefits, then even if a project can meet its financial obligations, it may not be sound or desirable [24, 25].

Quantifying intangibles is highly subjective: it is very specific to the country, culture, and project. Therefore, the discussions in this paper on economic aspects of renewable energy systems will be limited to the tangible part of the overall picture. Assuming that social benefits of a project are at least equal to (if not greater than) the social costs, the information documented in this paper will give a lower bound for the value of renewable energy systems.

In its simplest form, the cost of energy generated by a renewable (non fuel-burning) energy system is obtained by adding the capital recovery cost and O&M cost per unit of energy [26].

Typical, calculations are made on an annual basis and the cost of energy is given as:

$$C = \left[\frac{r(1+r)^n}{(1+r)^n - 1}\right]\left[\frac{P}{87.6K}\right] + [O\,\&\,M]$$

According to [Ref.27] (1)

$$C = \left[\frac{r(1+r)^n}{(1+r)^n - 1} + m\right]\left[\frac{P}{87.6K}\right]$$

According to [Ref.1] (1a)

Where

C=Cost of energy in U.S. cents/kWh

(or generation cost in U.S. cents/kWh)

k=Annual capacity factor in per-unit

(defined in equation (2) below)

(also known as plant factor or load factor or annual average energy production factor)

n=Amortization period, years

m=fraction of the capital cost needed/year for operation and maintenance of the unit.

O&M=Operation and maintenance cost in U.S. cents/kWh

P=Installed (capital) cost in U.S.$ / kW

r=Fixed annual interest in per-unit, i.e. (percent/100)

Actually the amortization period is usually equal to the lifetime of the energy system. Capacity factor refers to the ability of the system to generate energy on an annual basis. It is found using

$$k=\frac{Energy\ generated\ in\ kWh/year}{(System\ \ rating\ in\ kW)(8760\,h/year)} \qquad (2)$$

Inclusion of the cost of fuel (which could be biomass) requires the addition of (0.3413 f/n) to the right hand side of equation (1),

Where

f=Fuel cost in U.S. & per million Btu at the generation site, and

η=Overall efficiency of the plant in per-unit

$$\eta=\frac{3413\,Btu/kWh}{Heat\ \ rate\ in\ Btu/kWh} \qquad (3)$$

O&M costs are usually estimated on the basis of data collected from operating systems. Obviously, valid projections can be made based on the potential improvements in system technologies and operating strategies.

Although simple and useful, equation (1) is based on several assumptions. **First of all**, it assumes that the system is simply on “energy displacer” and no firm capacity can be expected from it. In other words, the system is given only “energy credit” and no “capacity credit”. This results in a conservative (high) estimate of the cost of energy. Capacity credit, if justified and accounted for, will decrease the cost from the value obtained from equation (1). Procedures are available to estimate the capacity credit based on system reliability concepts.

Secondly, it assumes that there is no escalation in O&M costs during the amortization period and that there is no general inflation.

Thirdly, influences of the tax structure and insurance costs are not included.

Finally, the depreciated (salvage) value of the plant at the end of the amortization period is assumed to be zero. This also makes the cost values high. But because of the balancing effects of the different assumptions, the cost of energy values found using this simple equation might come fairly close to the values obtained using more detailed procedures [27].

Step – I

The cost of energy generated by any energy system that does not require fuel is solely due to the amortization of the capital and operation and maintenance, if taxes and insurance charges are neglected. This cost can be expressed from equation (1) as

$$C = \left[\frac{r(1+r)^n}{(1+r)^n-1}+m\right]\left[\frac{P}{87.6K}\right] \qquad (4)$$

Equation (4) is plotted in Graphs 1 and 2 for plant factors ranging from 0.1 to 1.0. These charts can be used to obtain a quick estimate of the generation cost for non fuel-burning energy systems.

ASSUME DATA

If a wind-electric system costs = 1500 $/kW and is located in a site yielding a plant factor of 0.3, then the generation cost (for an annual interest rate 10%) can be obtained at 20 years amortization period and O&M cost is 5% of capital per year. We can also plot the graph after obtaining different data at 7.5% and 5% interest rate. Data Table is given in Table 1. P=1500 $ /kW, k = 0.3, r = 0.1, m = 0.05, n = 20

$$C = \left[\frac{0.1(1+0.1)^{20}}{(1+0.1)^{20}-1}+0.05\right]\left[\frac{1500}{87.6\times0.3}\right]$$

$$= \left[\frac{0.67274}{5.7274}+0.05\right]\left[\frac{1500}{87.6\times0.3}\right]$$

$$= [0.11746 + 0.05]\left[\frac{1500}{87.6\times0.3}\right]$$

$$= (0.16746)\left[\frac{1500}{87.6\times0.3}\right]$$

C = 9.5cents/kWh=6.08/kWh

(According to equation (1) (a) or (4), we get) [1 dollar=INR (Indian rupee) 64.03, 1 dollar=100 cents][28]

But, According to equation (1), we get, C=9.6 cents/kWh, which is slightly higher cost. So we can use for better result equation (1a) everywhere.

However, in evaluating the various options for supplying energy for remote and rural applications in the developing countries, the cost of energy obtained from renewable energy sources is often compared with the cost of generation using small diesel electric units (also known in the literature as auto generation). The cost of energy obtained from diesel units can be expressed as:

$$C = \left[\frac{r(1+r)^n}{(1+r)^n - 1} + m \right] \frac{P}{87.6K} + FD \tag{5}$$

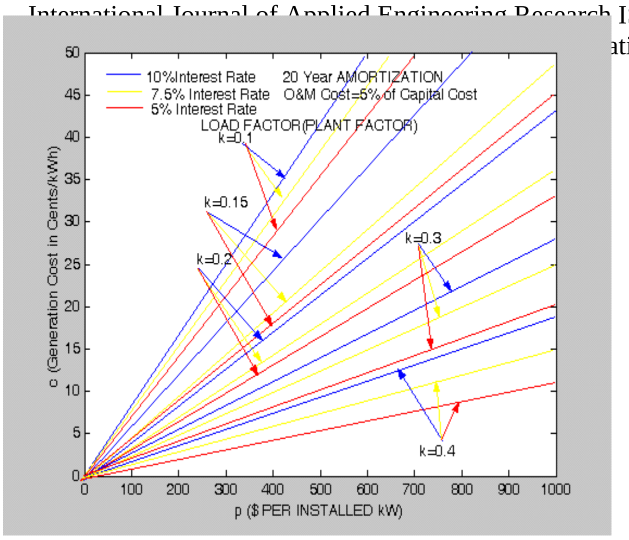
Where D is the diesel consumption in liters/kWh and F is the diesel cost in U.S. cents/liter.

Table 1

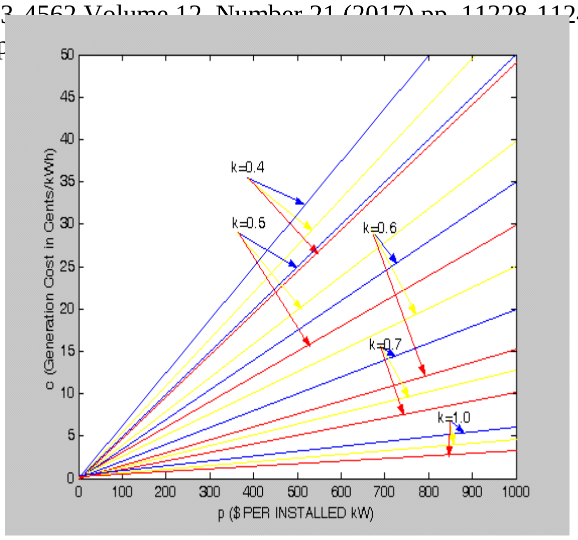
20 years Amortization (i.e. n = 20), O&M cost: 5% of capital cost (i.e. m = 0.05)

At given P (say 1500 $/ kW)

Sl. No.	No. of sets of data	k	r	C(cents/kWh)/(INR/ kWh)	Formula
1.	1	0.1	5%	22.33/14.29	$C = \left[\frac{r(1+r)^n}{(1+r)^n - 1} + m \right] \left[\frac{P}{87.6K} \right]$
			7.5%	25.35/16.22	
			10%	28.66/18.34	
2.	2	0.15	5%	14.89/9.5	
			7.5%	16.90/10.81	
			10%	19.11/12.23	
3.	3	0.2	5%	11.164/7.45	
			7.5%	12.67/8.1	
			10%	14.33/9.17	
4.	4	0.3	5%	7.44/4.76	
			7.5%	8.45/5.4	
			10%	9.55/6.11	
5.	5	0.4	5%	5.58/3.57	
			7.5%	6.335/4.05	
			10%	7.166/4.58	
6.	6	0.5	5%	4.46/2.85	
			7.5%	5.068/3.25	
			10%	5.73/3.66	
7.	7	0.6	5%	3.72/2.38	
			7.5%	4.224/2.74	
			10%	4.777/3.05	
8.	8	0.7	5%	3.2/2.04	
			7.5%	3.62/2.31	
			10%	4.09/2.61	
9.	9	0.8	5%	2.79/1.78	
			7.5%	3.17/2.02	
			10%	3.58/2.29	
10.	10	0.9	5%	2.48/1.58	
			7.5%	2.82/1.80	
			10%	3.18/2.03	
			7.5%	2.53/1.61	



Graph 1: Generation Costs for non fuel-burning energy system (0.1 ≤ k ≤ 0.4)



Graph 2: Generation Costs for non fuel-burning energy system (0.4 ≤ k ≤ 1.0)

SOCIO-ECONOMIC ASPECTS

The concepts of "development" and "quality of life" are very closely tied to the socio-economic setting of the individual concerned. This is especially true with a rural populace with centuries-old traditions and customs and this puts an extra burden on those advocating the introduction of renewable energy sources and energy systems in the rural areas of developing countries.

Many demonstration programs have been set up in villages around the world that, while providing interesting news stories, do not have any chance at all of being replicated over many additional villages for purely economic reasons. They in fact do a disservice in that they provide a source of rising expectations with no possibility of subsequent fulfillment. This dilemma is always faced by those persons attempting to improve the energy situation in remote rural areas of developing countries.

Unfortunately, conventional fuels are rapidly becoming out of reach for non-OPEC developing countries simply because of price or the availability of foreign exchange or both. Therefore, if the villager is to have energy at all, it must be of a variety that is locally available renewable energy sources. It is generally not realistic to expect that complete energy systems be manufacturable in the developing countries, but some components may be. It is very important in energy planning in any developing country to determine what can be done at home and what is not practical to do at home. It is at this point that participation of local educational institutions becomes vital. Moreover, any energy technology anywhere has continual operating problems and requires some constant attention. Local educational institutions can do an excellent job of taking care of the energy systems in their region and in training personnel to perform such jobs. Often, pilot programs are not needed to demonstrate that a particular technology works. Rather, pilot programs are needed to identify the day-to-day operating problems of complete energy systems, to understand the interface problems that may exist between devices and between local customs and system operating requirements, and to gather meaningful solutions to these problems. Once again, the importance of the participation of local education institutions is evident.

Any attempt that will not improve the villager's basic living environment but will help only the already rich will not instill hope in the minds of the rural poor. Therefore, providing energy to improve the basic living environment of those who need it the most should have highly priority. This must be followed by the using of energy to improve agricultural productivity and, eventually to the buildup of rural agro-industrial structures. At this point, economic multiplier effects are expected to come into action, resulting in tangible long-term benefits for everybody the rural areas and for the nation as a whole.

It is well known that many developing countries have millions of unemployed and underemployed people, mostly living in the two million villages of the world. Establishment of rural energy centers along with the ensuing multiplier effect should create a large number of work opportunities in rural areas. This should help mitigate the inner conviction of hopelessness to millions around the world and raise the level of rural life. Since health and well being of cities depend on the health and well being of rural areas, overall benefits of the approach in this paper could be immense.

HYBRID RENEWABLE ENERGY SYSTEM (HRES) – A CONCEPT

Matching the diverse characteristics of the renewable energy resources to widely varying rural needs in facilitated by employing integrated energy systems. Both tandem and cascaded approaches have been proposed to accomplish this objective. Thus two approaches have been suggested for the utilization of several manifestations. In the first approach, all the resources are converted into one form (usually electrical) for storage (usually in batteries) and distribution to consumers. The second approach advocates the integration of benefits at the user's end. A hybrid renewable energy system, which is shown in Figure 3, recommended as a combination of wind energy, solar energy, biomass energy

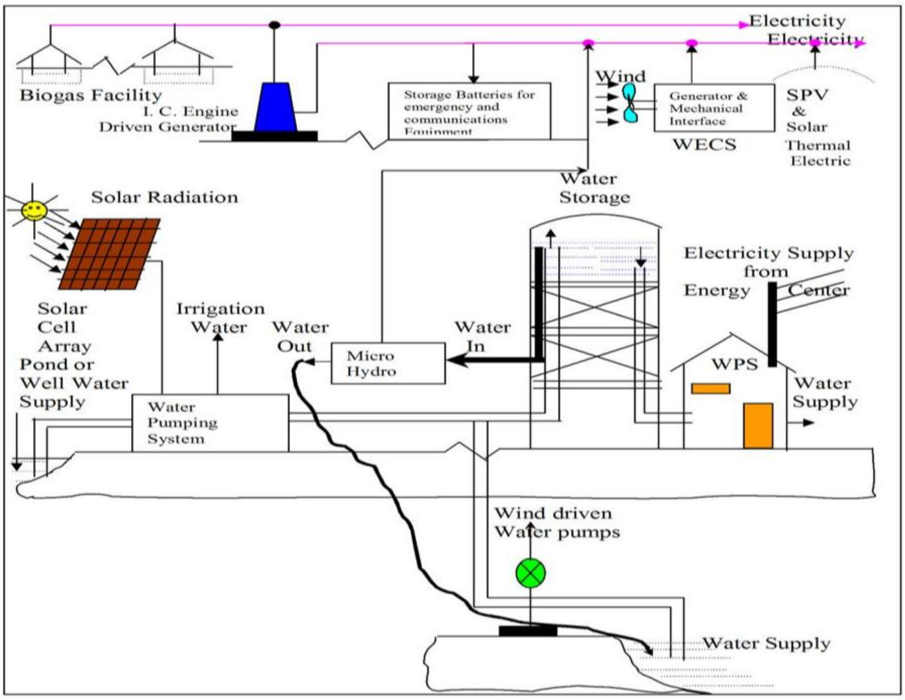


Figure 3: Schematic diagram of rural energy center to harness renewable energy sources in the Hybrid Form.

and apart of small hydropower (micro hydro). The objective is to supply the basic needs of the rural people in the most economic and appropriate manner. In other words, the available resources and the energy conversion devices should be matched to the basic needs to achieve an improvement in the living environment in rural areas. Figure 1 illustrates one possible combination of devices and their interconnection suitable for a hybrid rural energy center. Wind-driven water pumps and solar cell-driven water pumping stations pump water for storage in an overhead tank. A small hydroelectric (micro hydro) unit can be used as needed to convert the potential energy of the stored water into electrical form and the water re-circulated as in the case of pumped hydro stations. When necessary, irrigation water can be supplied directly as shown in Figure 3. Domestic and portable water supply for the village is drawn from the overhead water storage as illustrated. A community biogas facility with sufficient gas storage constitutes an important component of the energy center. Biogas can be directly supplied from this facility for cooking and other needs of the villagers. The micro hydro unit and wind-electric conversion system as shown assist this electrical supply. Storage of electrical energy in batteries is provided only to operate the emergency and batteries are provided only to operate the emergency and communications and educational equipment. The bulk of the energy storage, however, is in the form of biogas storage and as potential energy of water stored in the overhead tank. In the future, additional devices can be incorporated, as the occasion warrants**.** Remote clusters of four to five villages are common in developing countries. Often, such clusters are not electrified because of the low load factors presented by such loads and also because of the expense involved in constructing long distribution lines for existing utility grids. Such clusters can be energized by establishing an energy center of the type described previously in one of the villages and by installing a distribution line connecting all the villages as shown in Figure 4.

Depending on the local conditions, availability, and terrain, windmill farms, micro hydro units aided by solar and/or wind energy, self Micro hydro/Pico hydro, photovoltaic devices, and other possible energy conversion units (for example, devices suitable for utilizing locally available agriculture waste and other biomass) can be added in times as illustrated.

BENEFITS OF HYBRID RENEWABLE ENERGY SYSTEMS (HRES)

In this approach, each of the energy conversion devices is dedicated to meet a specific need. While in an overhead reservoir, photovoltaic arrays may be charging a small battery bank used to power educational and communications equipment and a biogas facility might be supplying biogas for cooking. Thus the only "integration" that accrues is the integration of benefits at the user's end. After all, the objective is to supply the basic energy needs of remote rural communities in the most economic and appropriate manner.

The HRES is more reliable for development of rural areas become of the following considerations:

i. Increase in agriculture output due to availability of energy and fertilizer.

ii. Timely availability of critical inputs to villages in terms of energy and commodities.

iii. Generate more employment in villages.

iv. Improving the life style and checking the migration of masses to cities.

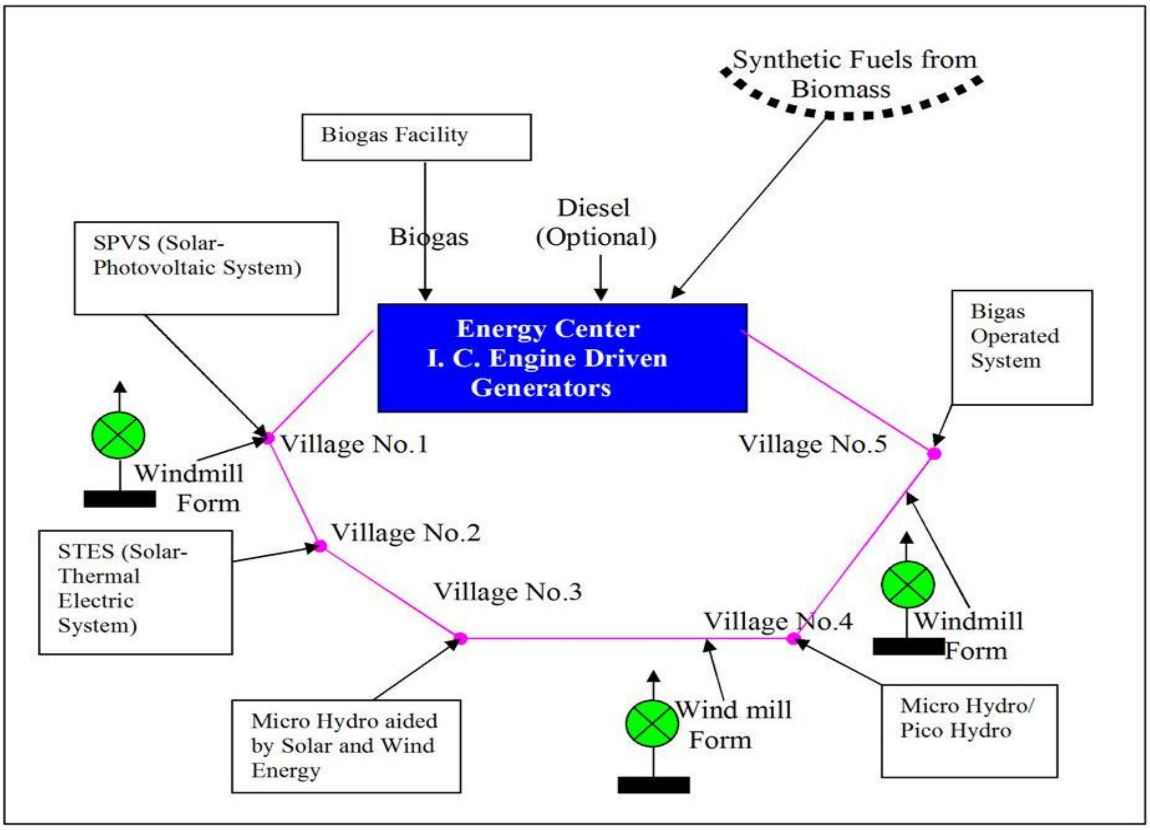


Figure 4: Scheme to energize a small cluster of Villages

CONCLUSIONS

It is found out that the standard of living of rural peoples will be increased by utilizing renewable energy sources as hybrid renewable energy system. After establishment of the rural energy centers employment opportunities will be increased. The improvement in living standard will stop the migration of peoples from rural area to township will be stop. As a result social as well as the economic conditions of the villages will improve. HRES are more reliable for the development of rural remote areas in the developing countries.

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REFERENCES

[1] R. Rama Kumar and W.L. Hughes, 1981, "Renewable Energy Sources and Rural Development in Developing Countries", IEEE Trans. on Education, Vol. E-24, No. 3, pp. 242-251.

[2] R. Revelle, 1979, "Energy Sources for Rural Development", Energy, Vol. 4, pp. 969-987.

[3] R. Rama Kumar, 1977, "Technical and Socio-Economic Aspects of Solar Energy and Rural Development in Developing Countries", Solar Energy, Vol. 19, pp. 643-649.

[4] L. M. Cook, 1981, "The Energy Crisis: Going, Going, but not Quite Gone", IEEE Trans. on Industry Applications, Vol. IA-17, No. 6, pp. 548-551.

[5] W. Sassin, 1980, "Energy", Scientific American, Vol. 243, No. 3, pp. 18-132.

[6] R. Rama Kumar,1983, "Renewable Energy Sources and Developing Countries", IEEE Trans. on Power Apparatus and Systems, Vol. 102, No. 2.

[7] J. K. Parikh, 1979, "Renewable Energy Options: What could Developing Countries expect from them?", Energy, Vol. 4, pp. 989-994.

[8] National Academy of Sciences, 1981, "Energy for Rural Development-Renewable Resources and Alternative Technologies for Developing Countries", Report, 1976 and Supplement.

[9] R. Rama Kumar et al., 1969, "A Wind Energy Storage and Conversion System for use in Under Developed Countries", Proceeding 4th Inter Energy Conference (IECEC), pp. 606-613,Washington, D.C.

[10] S. Z. Mozumber, 1981, "The Energy Situation in Bangladesh and a strategy for Future Development", Energy, Vol. 6, No. 8, pp. 809-816.

[11] S. M. A. Ibrahim, 1979, "*Energy in Egypt: Resources, Uses and Outlook to 2000*", Energy, Vol. 4, pp-1069-1077.

[12] R. Revelle, 1976, "Energy Use in Rural India", Science, Vol. 192, pp. 969-975.

[13] C. L. Gupta, et al., 1980, "Domestic Energy Consumption in India (Pandicherry Region)", Energy, Vol. 5, pp. 1213-1222.

[14] V. Smil, 1979, "Energy Flows in the Development World", American Scientist, Vol. 67, No. 5, pp. 522-531.

[15] H. P. Garg, 1975, "Year Round Performance Studies on a built-in storage type solar water heater at Jodhpur", India, Solar Energy 17, 167.

[16] G. D. Mehta, 1975, "Non Convicting Solar Ponds", Technical Report ETG-4, Hydronautics, Inc., Laurel, Maryland.

[17] W. C. Dickinson et al., 1976, "The Shallow Solar Pond Energy Conversion System", Solar Energy 18, 3.

[18] R. Rama Kumar et al., 1975, "Wind Energy Utilization Prospects", Proceeding 21st Annual Meeting of the Institute of Environmental Sciences, Vol. I-Energy and the Environment, pp. 138-142.

[19] C. R. Prasad et al., 1974, "Bio-Gas Plants: Prospects, Problems and Tasks, Economic and Political Weekly", Vol. IX, Nos. 32-34, Special Number, pp. 1347-1364.

[20] R. Rama Kumar, 1976, "Utilization of Solar and Wind Energy to Improve the Living Environment in Less Developed Countries", Proc. 22nd Annual Technical Meeting of the Institute of Environmental Sciences, pp.314-318, Philadelphia, Pennsylvenia.

[21] Rural Electrification, a World Bank Paper (1975)

[22] R. Rama Kumar, 1976, "Wind Driven Field Modulated Generator Systems", Proceeding 11th Inter Energy Conv. Engg. Conf. (IECEC), pp. 1766-1772, State Line, Nevada.

[23] C. Weiss and Simon Pak, 1976, "Developing Country Applications of Photovoltaic Cells", Paper presented to National Solar Photovoltaic Program Review Meeting Sponsored by ERDA, Washington, D.C.

[24] J. J. Fritz, J.M. Knapp, and H. Jones, 1984, "Economic and Financial Feasibility", in Small and Mini Hydropower Systems, New York: McGraw-Hill.

[25] A.V. Desai (Ed.) , 1990, Energy Economics, New Delhi, India: Wiely Eastern Ltd.

[26] "Engineering Economic Analysis: Overview and Current Applications", IEEE Publication No. 91EH0345-9-PWR, 1991.

[27] R. Rama Kumar et al., 1993, "Economic Aspects of Advanced Energy Technologies", Proceeding of the IEEE Vol. 81, No. 3, pp. 318-332.

[28] https://economictimes.indiatimes.com [Accessed on : 18.09.2017]