



PERGAMON

Renewable Energy 17 (1999) 255–263

**RENEWABLE
ENERGY**

Technical note

Proper utilization of solar energy in Bangladesh: effect on the environment, food supply and the standard of living

Saifull Islam*, Ain-Ul Huda

Physics Department, University of Dhaka, Dhaka-1000, Bangladesh

Received 20 February 1998; accepted 1 May 1998

Abstract

The only really sustainable form of energy is solar energy. The densely populated tropical countries can do very well from this completely sustainable energy source without any novel technologies. Most of the commercial energy used world-wide is supplied by using non-renewable resources. Environmental damage—global warming, ozone hole, noise, chemical and radioactive waste—is due to high energy use. Environmental deterioration is a direct consequence of wealth generated and sustained by extremely cheap fossil fuel. The price of fossil fuel does not include the cost for the deterioration of the environment. We show in this paper that even a densely populated country like Bangladesh can attain a high standard of living by a proper utilization of solar energy. We suggest that poor tropical countries should mobilize their resources to develop solar technology. © 1999 Elsevier Science Ltd. All rights reserved.

1. Introduction

Energy and physical resources are necessary for economic development and they are not scarce. The amount of energy received by the earth from the sun is 175,000 TW (1 TW = 1 million million Watt). The total commercial energy used for all human activities in the world is now less than 15 TW. What is scarce is technology. Technology is not only machines, it is also knowledge to run these machines. Knowledge is also needed for the organization of the distribution of goods and services. It is knowledge

* Corresponding author. International Study Group on Self-Organization, Düsseldorfstr 13, 80804 München, Germany.

that is scarce in the developing societies. Many developing societies waste whatever resources they have because they do not have well-trained financial experts, scientists, technologists, managers and jurists. The inappropriate application of technology often creates an artificial scarcity of resources.

The solar constant (1.360 kW/m^2) is the rate at which solar energy is received per unit area at the outer limit of the earth's atmosphere. Because the cross-sectional area and the total surface area of the earth differ by a factor 4, the *average* energy flux incident on the earth is one-fourth the solar constant, or 0.340 kW/m^2 . Of the incoming solar radiation, 49% is absorbed and reradiated or backscattered by the atmosphere, 4% is backscattered from the ground, and 47% or 0.160 kW/m^2 is absorbed by the earth's surface [2]. It should be noted that this is an average over day and night and over all latitudes. In Bangladesh this average is 0.193 kW/m^2 [6].

Bangladesh has an area of about $147,500 \text{ km}^2$ or $147.5 \times 10^9 \text{ m}^2$. This means that Bangladesh receives a constant supply of 28 TW energy from the sun. This is about 235 kW per capita for a population of 120 million. If we consider that the total amount of commercial energy use in Bangladesh is only 0.05 kW per capita this is a huge amount of energy. A feasible utilization of solar energy is suggested in this paper to raise the standard of living in Bangladesh. It is assumed that the population of Bangladesh is going to be stabilized at 200 million.

2. Estimation of future energy demand in Bangladesh

For the estimation of final energy demand in Bangladesh, the whole consumption activities are divided in five categories [5]: (1) Nutrition; (2) Housing; (3) Private mobility; (4) Other private consumption; and (5) Public Consumption. In the following considerations we assume that, in the next twenty years, the energy efficiency can be doubled compared to Germany *at present*. This assumption is justified because Germany can increase the energy efficiency by a factor of two, by replacing old machines, household gadgets, automobiles, chemical plants, and by a better use of existing technologies within the next twenty years [1]. This is not being done because fossil fuel is extremely cheap in comparison to per capita income in rich countries.

In this section energy needs are estimated sector by sector. In these estimations a standard of living found today in Western Europe is taken as model. Average energy consumption in Western Europe today is about 5 kW per capita per year. In the U.S.A. it is 11 kW. As discussed above, the energy efficiency can be increased in Western Europe by a factor 2. So that within the next twenty years the energy demand in Western Europe can be decreased to 2.5 kW per capita per year without any loss in the standard of living. In this paper the final energy demand in Bangladesh is considered to be about 1.5 kW per capita per year. It will be shown in the sector by sector discussion why Western Europe uses more energy than what is necessary.

For the nutrition sector we first have to determine whether Bangladesh can be self-sufficient in grain production by producing one crop annually. At present, on the average, Bangladesh produces more than two crops per year. As a consequence the country is facing the following serious environmental problems:

- (1) Fertility of the soil is dwindling very fast due to irrigation: sulphur and zinc are being leached.
- (2) Water table becomes very low in dry season.
- (3) Irrigation in dry, hot season increases insects including mosquitoes.
- (4) Fish production is dwindling because of the use of artificial fertilizers.
- (5) Water pumps and artificial fertilizers use non-renewable resources.

The major rice crop in Bangladesh has always been the *Amon*. The productivity of the traditional variety was very low. *Amon* is still the major crop of the country with an average productivity of 1.63 t/ha (tons per hectare). This variety is produced on about 5.7 Mha. The hectareage of high yield *Boro* variety is increasing rapidly due to the availability of irrigation facilities and artificial fertilizers. At present this is about 2.6 Mha, with an average productivity of 2.6 t/ha. The traditional *Boro* was cultivated on low lands where irrigation was not necessary. Another major crop, *Aus*, is being abandoned because of low productivity.

To estimate the amount of paddy production in Bangladesh, we need to know the solar insolation and the photosynthetic efficiency of rice plants. These are given in Tables 1 and 2. In our calculation, only the ripening stage of paddy is taken into account. Solar radiation at the reproductive stage has the greatest effect on grain yield, the next highest effect is at the ripening stage. Solar radiation of 150 W/m² makes yields of 5 t/ha or more possible. Less solar radiation during ripening is required because more solar radiation reduces the percentage of filled spiklets [7]. Since in Bangladesh the average solar radiation is always over 160 W/m² and since during the ripening period of *Amon* (December) the solar radiation is only about 13% higher than 150 W/m², maximum yield can be achieved with the *Amon* paddy. Due to lower temperature there are less insects during its ripening. It is also easier to dry,

Table 1
Monthly averages of solar insolation [6], rainfall and temperature [4] in Dhaka, Bangladesh

Month	Solar insolation W/m ²	Rainfall (mm)	Temperature (°C)	
			Maximum	Minimum
January	179	1	25	12
February	203	47	28	13
March	230	0	33	16
April	217	25	35	23
May	236	153	34	25
June	214	132	32	26
July	161	386	31	26
August	163	182	31	26
September	188	158	31	26
October	192	83	31	24
November	176	2	29	18
December	162	0	26	13

Table 2
Photosynthetic efficiency for the production of paddy

	Available light energy (%)
At ground level	100
55% loss as a result of 400–700 nm light being photosynthetically active radiation	45
40% loss due to reflection, absorption and transmission by leaves	27
75% loss representing quantum efficiency requirement for CO ₂ fixation at 680 nm light and that energy content of 575 nm light is the radiation peak	6.75
40% loss due to respiration	4
75% of absorbed energy during ripening is transformed into paddy [7]	3

store and transport the rice after the harvest because it does not rain in December (Table 1).

Amon is harvested in the beginning of December. The average solar insolation during its ripening period (30 days) is about 170 W/m². At a photosynthetic efficiency of 3% we expect *Amon* paddy production per ha for a 30 day ripening period from the following relationships:

$$\text{Photosynthetically fixed energy in paddy} = 170 \text{ W/m}^2 \times 10,000 \text{ m}^2/\text{ha} \times 30 \text{ days} \times 86,400 \text{ s/day} \times 0.03 = 132.2 \text{ GJ/ha}$$

$$\text{Energy content of paddy} = 16.5 \text{ GJ/ton}$$

$$\text{Paddy yield} = 132.2/16.5 \text{ (t/ha)} = 8 \text{ t/ha}$$

We do not expect this level of production, due to several climatic factors, i.e. suboptimal temperature, flood, cyclone and water shortage. Additionally a part of this harvest is eaten by rodents, birds and other animals. Then there is also the problem with insects. Averaged over the whole of Bangladesh, we expect a production level of 75% of 8 t/ha or 6 t/ha. The ratio of dry rice weight to husk weight is 67%, so rice production will be 4 t/ha. This is only 50% higher than present yield (2.6 t/ha) of *Boro*.

Area available for rice production in Bangladesh is about 5.6 Mha. As some fields are used for double, sometimes even triple, cropping, rice is produced effectively on 11 Mha. We mentioned earlier that multiple cropping is causing serious environmental problems. From the above calculation it is apparent that efficient single cropping of *Amon* on 5 Mha will yield 20 Mt. For a population of 200 million this will result in 274 g per day per capita. With the increase in standard of living carbohydrate intake reduces, so that 274 g per day of rice will be sufficient. It is to be noted that we have not taken into consideration the production of wheat (present hectareage 0.6 Mha) and other cereals. We just wanted to show that Bangladesh can definitely feed a population of 200 million adequately. Food policy in Bangladesh must also concentrate on the supply of fish, poultry, dairy products, meat and vegetables; and their storage, preservation, and transport.

There is ample scope of increased production. We have shown above that an average yield of 4 t/ha for *Amon* rice is feasible (present productivity of *Boro* is 2.6 t/ha). Whereas the yield of potato is already 11 t/ha, sugarcane 40 t/ha, banana 16 t/ha, vegetables 8 t/ha. Amount of land used for fruit and vegetable production in Bangladesh is very low now, only 0.2 Mha. Potato is produced on 0.13 Mha.

The energy input in the nutrition sector is required for fertilizer, transport, storage and packaging. This is estimated to be 2000 kWh per capita per year. In Germany this sector requires 8000 kWh (Table 3). There are various reasons for it. But one of the main reasons is extremely high energy content of considerable amount of food that a cold country like Germany cannot produce over the whole year. Take the case of tomato: Tomato from the Canary Islands, when in German market, has 83 times as much embodied energy in it as the locally produced tomatoes. The figures are [5]: local outdoor production 0.56 kWh/kg, local greenhouse production 15.3 kWh/kg, Canary Island tomatoes 46.7 kWh/kg.

In Germany, from the total of 12,500 kWh [3] needed in the housing sector, 7400 kWh is for space heating and 1100 kWh for warm water. Energy needed for the construction and maintenance of private dwellings is 2500 kWh per capita per year of primary energy. This figure has to be deflated by a factor of 2.8 as we consider only photovoltaic electrical energy for Bangladesh. The efficiency of generation of electricity from primary energy is about 35% in Germany. For Bangladesh thus a per capita energy input of 1000 kWh electrical energy will be sufficient for the construction and maintenance of dwellings. For lighting, cooking, washing, and cooling the energy needed in Germany is 1000 kWh per capita per year of electrical energy. Here, considerable improvements can be achieved by replacing the existing household appliances with already available energy efficient gadgets [1]. Energy required for these activities is considered to be 500 kWh per capita per year in Bangladesh. With the improvement of the standard of living Bangladesh will need about 1000 kWh for

Table 3
Energy use in Bangladesh (projected) and Germany (actual)

Sector	Projected energy use in Bangladesh (kWh/capita-year)	Present energy use in Germany (kWh/capita-year)
1. Nutrition	2000 (15.4%)	8000 (15.1%)
2. Housing	3000 (23.1%)	15,000 (28.3%)
3. Private mobility	3000 (23.1%)	12,000 (22.6%)
4. Other private consumption	3000 (23.1%)	11,000 (20.8%)
5. Public consumption	2000 (15.4%)	7000 (13.2%)
Total	13,000	53,000

1. German energy input can be halved within the next 15–20 years, mainly by an efficient use of energy [1]. The other reason for low input in Bangladesh is because electricity will be generated by photovoltaic method. Most of the energy used in Bangladesh will be in the form of electricity thus generated.
2. In Germany, primary energy used for generating electricity is about 2.8 times as high as electrical energy available for final use.

air-conditioning and ventilation. The total energy requirement for the housing sector will thus be 3000 kWh per capita per year.

Private mobility includes transportation for going to workplace and schools, recreational travelling, shopping etc. The energy cost of construction and maintenance of roads, railway tracks, airports, sea and river ports, stations, automobiles, boats, rolling stocks, are included in the estimation. Travelling on duty, apart from daily journey to workplace, is taken care of in the following two sectors. For 220 working days and living about 5 km away from workplace amounts to a travelling of 2200 km per capita per year, recreational travelling on surface is another 4000 km. With increased standard of living we expect 5000 km on the average of travelling by air—one trip every three years to Europe or Japan. Energy need will be 1200 kWh for surface travelling and 1800 kWh for air travelling. Total energy needed in the private mobility sector will thus be 3000 kWh. In Germany this figure is 12,000 kWh [3]. The main reason for this is the German dependence on automobile. Because the average occupancy of a private car in Germany is only 1.4, this mode of transportation requires at least double as much energy per capita than the public transport system. Travelling alone in automobile is more energy intensive than flying by commercial aircraft.

Other private consumption includes gadgets, sports articles, furniture, holidays, cosmetics, jewellery, clothing, insurance premiums, medical care etc. In other words, the energy needed in this sector is used by the whole of industrial, manufacturing, commerce and other private service sectors of the economy. In Bangladesh we estimate this to be 3000 kWh. The high figure in Germany (12,000 kWh) needs no explanation as it is a characteristic of rich consumption-oriented society.

Public consumption includes energy cost for providing hospitals, schools, police, military and public administration, etc. Energy requirement for the provision of public services in Germany is 7000 kWh per capita per year. This figure has to be deflated by a factor of 2.8 as we consider only photovoltaic electrical energy for Bangladesh. The efficiency of generation of electricity from primary energy is about 35% in Germany. For the provision of public services at a level of Germany would thus require 2500 kWh per capita per year of electrical energy. As we have discussed in the housing sector the main energy cost in the public sector is space heating and warm water. We consider that 2000 kWh per capita per year will be sufficient for the provision of public services in a densely populated country like Bangladesh where less per capita infrastructure is required than in Germany.

3. Land requirement for the production of solar electricity in Bangladesh

All needed energy except for aviation and maritime transport, natural gas for fertilizer and chemical feedstock is assumed to be in the form of photovoltaic electricity. The reason for assuming this, is because the distances to be covered in Bangladesh are small, so that electric cars can be used. Public transportation will be serviced by electric trams, trains, buses and trucks.

Let us now estimate the area of land required for photovoltaic generation of

electricity. Bangladesh receives 193 W/m^2 of sunlight. The efficiency of solar cells making electricity is already about 10%. It is, of course, still very expensive—about 10 times as much as a coal-fired power plant. On the other hand photovoltaic technology is much less polluting and it is sustainable. It is expected that the cost will come down rapidly once the economy of scale comes into operation.

Energy need in the housing sector will be 3000 kWh per capita per year, or 342 W (3000 kWh/8760 h) per capita continuous. With a 50% over capacity this is about 500 W. At an efficiency of 10%, about 25 m^2 ($500 \text{ W}/20 \text{ W m}^{-2}$) per capita of surface area will be needed for solar cells supplying this amount of energy. We assume a land use of 75 m^2 per capita for housing (Table 4). It is not unreasonable to assume that housing sector can use its own land for generating electricity.

Public sector energy need is 2000 kWh/capita. With 50% over capacity it is 340 W/capita continuous power. Land requirement will be 17 m^2 /capita for the generation of electricity. This should also pose no problem, because public services are provided in large structures.

Of the total energy need of 13,000 kWh, 5000 kWh have already been taken into account; 3000 kWh for housing and 2000 kWh for public consumption. Of the rest 8000 kWh, non-electrical energy need is equal to 1800 kWh for aviation, 700 kWh for maritime transportation and 100 million m^3 natural gas for fertilizer and chemical feedstock. Half a cubic metre per capita of natural gas has an energy of about 5 kWh, which is negligible. So we need to estimate land requirement for the generation of 5500 kWh ($8000 - 1800 - 700 = 5500 \text{ kWh}$). With 50% over capacity, continuous energy need is equal to 940 W ($5500 \times 1.5 \text{ kWh}/8760 \text{ h}$). Land requirement at 20 W/m^2 will be 47 m^2 /capita or 9400 km^2 for a population of 200 million.

4. Fuel requirement in Bangladesh

Apart from 100 million m^3 of natural gas for fertilizer production and chemical feedstock, fuel requirement in Bangladesh is 2500 kWh for aviation and maritime transport sector. One barrel of petroleum has an energy of 1700 kWh. So the fuel

Table 4
Suggested land utilization in Bangladesh for a population of 200 million people

Activity	Area (square kilometer)	Percent of total area
Grain production	50,000	33.9
Other food production	22,500	15.3
Housing	15,000	10.2
Infrastructure	20,000	13.5
Forest	20,000	13.5
Park, river, waterlogged areas	10,000	6.8
Electricity (photovoltaic) generation	10,000	6.8
Total	147,500	100.0

need will be 1.5 (2500/1700) barrels per capita per year. Bangladesh will have to import 300 million barrels per year for 200 million people. Because of the small size of the land Bangladesh cannot produce fuel for these sectors from plant biomass.

Biomass can be transformed into liquid fuel with an efficiency of 25%. If we assume that energy generating plants can, on the average, convert solar energy into biomass on 250 days a year at 4% efficiency (Table 2, second row from below), energy content of plant biomass will be:

$$193 \text{ W/m}^2 \times 250 \text{ days} \times 86,400 \text{ s/day} \times 0.04 = 167 \text{ MJ/m}^2 = 46.6 \text{ kWh/m}^2$$

Biomass converted to fuel will have an energy of 11.6 kWh (46.4×0.25). Land required for producing fuel will be about 215 m² per capita (2500/11.6) or 43,000 km² for a population of 200 million. Bangladesh cannot use this amount of land for fuel (Table 4). It is, however, interesting to note that the present population (120 million) of Bangladesh can be supplied with biomass fuel produced on 26,000 km² of land. Per capita rice availability will remain at 274 g, when cultivated on 30,000 km² with a productivity of 4 t/ha.

5. Conclusion

Even a densely populated (1355 inhabitants/km²) country can live rather well with a solar energy input of 80% with all the amenities that modern technology can provide. This does not even require any novel technology. Rich countries can afford to buy fossil fuel and they are used to a wasteful way of life. They will not initiate research for large scale utilization of solar energy. It is imperative that poor countries in the tropical regions mobilize their resources to develop technology for the utilization of solar energy if they want to increase the standard of living.

Acknowledgements

SI thanks Professor LM Nath, Chairman, Physics Department and Professor MS Chowdhury, Dean of the Faculty of Science for an invitation to a visiting professorship at the Physics Department of the University of Dhaka. We wish to thank the following persons for helpful discussions: Abdul Mannan Bhuiyan, Minister of Food and Agriculture, Government of Bangladesh, Dhaka; Dr Abdul Moyeen Khan, State Minister for Planning, Government of Bangladesh, Dhaka; Dr Ursula von Gierke, International Centre for Diarrhoeal Diseases Research, Dhaka; Professor Badrun Nahar, Institute of Nutrition and Food Science, University of Dhaka; Abdul Kabir, Schoolmaster, Syedpur Village, Monohordi, Narsingdi; Dr CS Karim, Bangladesh Atomic Energy Commission, Dhaka; Sayeef Fatehur Rahman, Sugar Cane Research Institute, Gazipur; Dr Md Zahrul Haque, Director General, and Dr Jiban Krishna Biswas, Bangladesh Rice Research Institute, Gazipur; Professor Abdul Hamid, Department of Agronomy, Institute of Post Graduate Studies in Agriculture, Gazipur.

References

- [1] Dürr H-P. In: Smith PB, Okoye SE, de Wilde J, Deshingkar P, editors. *The world at the cross-roads*. London: EarthScan, 1994.
- [2] Emiliani C. *Planet earth*. Cambridge: Cambridge University Press, 1992.
- [3] Global Challenges Network and Greenpeace Magazine. *Brauchen Sie die Energie Diät?* Hamburg, 1994.
- [4] Government of Bangladesh. *Statistical yearbook of Bangladesh*. Dhaka, 1994.
- [5] Greenpeace Schweiz und Verkehrsclub der Schweiz. *Persönliche Energie- und CO₂- Bilanz*. Zurich: Aktion Klimaschutz, 1992.
- [6] Hussain M, Aditya SK, Bhowmik NC, Das KC, Islam S, Khan FA, Mazumdar RK, Rahim A, Rasul MG. *A study of solar radiation in Dhaka, Bangladesh*. In: Saha H, Saha SK, Mukherjee MK, editors. *Integrated renewable energy for rural development*. New Delhi: Tata McGraw-Hill, 1990.
- [7] Yoshida S. *Fundamentals of rice crop science*. Manila: The International Rice Research Institute, 1980.