RENEWABLE ENERGIES IN RURAL AREAS

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Abstract:

Renewable energy utilisation is of specific importance, where other resources are not available or where they are in short supply. This is the case in most of the developing countries, mainly due to the distant location of many villages and the low income of the local population. In these regions people usually rely on the exploitation of the sources on hand, which is in accordance with their traditional way of life. But even if the inherited habits were adequate in the past, the actual population growth leads to a disproportionate use of resources. Thus, in many remote areas the depletion of natural reserves is increasing rapidly. Under theses circumstances applications based on contemporary renewable energy technologies (photovoltaics, wind energy conversion, biomass gasification, hyper filtration, etc.) can significantly improve the living conditions.

With emphasis on solar technologies this paper presents an overview of the current equipment for such life supporting strategies, dealing also with specific energy consumption figures and cost parameters. The compilation is mainly limited to solutions with stand-alone capabilities (off the grid) suited for low demand, which is nevertheless the most urgent issue to ease the situation of the people.

Depending on the local ambient conditions the potential of the various renewable energy resources – wind, hydraulic energy and biomass – may be different. Assessment of the most advantageous solution for a specific region may be an challenging effort. Anyway, for rural areas solar energy often is the first choice.

1. Introduction

In large parts of the world Renewable Energy (R.E.) sources present the only practicable option, other opportunities being scarce. Frequently, fossil fuel resources from “national” are lacking; but even if “national” reserves might be available, they often are too expensive or the transportation infrastructures insufficient, which also holds for any imported energy carriers. This illustrates the situation in many countries, where R.E. utilisation is envisaged as the only possible alternative.

The application tree (**Figure 1**) shows the most relevant R.E. utilisation and consumption schemes. Obviously various sources can be used to serve the several purposes or to fulfil a specific demand. Whenever electric energy is applicable (e.g. for lighting, or where mechanic energy is used to drive certain appliances), established techniques can be appropriate. Even, where other ways are established - be it the burning of liquid fuels for lighting or the use of animals to power pumps or for thrashing - an intensified utilisation of R.E. offers many opportunities.

The common practice to use firewood for cooking and lighting is one of the reasons of deforestation and of a rapid growth of arid areas. Given that, efficient use of energy and the switch to new concepts can be envisaged as an essential contribution to global environmental efforts.

Successful transition to such novel methods imposes a careful evaluation about the (local) availability and the expected potential of any renewable energy resources applied. Such assessment also requires a consideration about practical and financial aspects, accounting for proper techniques used. Very low population density and the subsequently large distances between settlements do not permit the extension of an electric grid beyond regional confines. Thus, in those regions solar radiation is supposed to present the most probable energy source for isolated applications in the near future. Thus - with respect to the mostly low specific energy consumption figures typical for such regions -, the equipment needed is rather small size. Nonetheless, for such components longevity, reliability, rigidity, and the maintainability by non-skilled labour present important features to be taken into account. This is especially true, when the systems are designed for stand-alone operation.

The argument related to costs is of at least similar importance. A compilation of yearly income figures (cross national product per capita) illustrates that even moderate investment expenditures can exceed the financial options of the individuals. Given that, system costs can be prohibitive for the dissemination of solar technologies. In view of that the reasons for the rather slow progress of the market introduction of R.E. systems are obvious, even if mature equipment for various purposes is available.

In **Table 1** some figures for selected countries have been compiled, showing the specific energy consumption, electricity generation, and the “equivalent” rating of an idealised photo-voltaic system to deliver an equivalent amount of electricity per year. A comparison of the gross domestic product with the investment costs needed for the supposed solar (PV) system makes the problems apparent: to finance a solar based energy infrastructure folks in some countries would have to invest the total per capita national product for years. This is only illustrating the financial side of the issue. It does not address the difficulties of adapting the energy system to the demand and the question of losses related to such measures, which usually includes the necessity of energy storage.

Table 1: Energy Consumption and Economic Parameters (p. cap. '94; selected Countries)

Country	**Energy Consumption**	**Electricity Generation**	**equiv. PV-Installation**	**Gross Domestic Product**	**PV-Installation Costs**
	kg OE / a * cap	kWh / a * cap	Watt $_{PEAK}$	$ / a * cap	$ / cap
Brazil	690	1734	1440	3370	7000
China	650	760	>800	530	4000
Ethiopia	21	24	15	130	80
India	240	374	>250	310	1300
Indonesia	393	239	>200	880	1100
Italy	2710	4525	4200	19300	20000
Mexico	1580	1470	1300	4010	6500
United Kingdom	3750	5600	8600	18400	>42000

2. Solar Home Systems and Small (domestic) Applications

Electricity generation figures in Table 1 reflect the global energy situation in the different regions: Whilst in the industrialised countries the data include the commercial and industrial energy demand (respectively: the data are dominated by this consumption, which is the basis of the gross national product figures), in some (poor) regions the energy required is needed to fulfil individual energy needs. According to this for countries with weak infrastructure it is suggestible to consider the domestic energy requirements as the relevant factors.

Accordingly, most appliances for solar applications serve domestic purposes, mainly in low power versions utilising photo-electric conversion. By combining electricity generating devices and storage capacities a high degree of reliability can be reached.

Recent technical development showed that such systems have reached a high degree of maturity. Accordingly, some governments intending to build up the rural infrastructure in their countries launched fundamental programs aiming at the distribution and marketing of solar systems for domestic appliances. Main argument for such programs is the large number of isolated settlements (which may in fact be located on separate islands, as is the case e.g. in the Philippines), so distant from each other one that centralised or grid-connected solutions are nor viable. Thus, with the exception of the neighbourhood of a few large cities any development must rely on stand-alone configurations.

Promotional efforts for such systems mainly count on financing schemes - in part by direct funding, subsidised loans (often by means of revolving funds), financial backing, reduced interest rates or by tax incentives. Sometimes also an encouragement for local enterprises is given to warrant proper servicing and maintenance of the systems.

Figure 2 presents a schematic sketch of the main components of a stand-alone PV system, including a small catalogue of customary appliances available from the shelf. The power required for such purposes varies with the different concepts.

2.1 Solar Lighting Systems and Battery Chargers

The so-called Solar Home Systems (SHS) are common in a power range between 20 Watts and some hundred Watts. Various configurations are available, from very simple "one way" to "multi-purpose" concepts, which include applications, where excess energy is used to charge external batteries (often providing a small additional income for the owner of the solar system).
Depending on the lay-out of the PV-array and the demand people may even use the opportunity to power small audio equipment or a low-power TV set utilising the solar source.

Stand-alone solutions are also available for communities and commercial purposes. From a technical point of view the main difference to Solar Home Systems lies in the higher installed power, which leads to some advantages also in the cost / benefit ratio.
When the output of the system exceeds about 3,5 kW, and / or when a larger number of consumers are connected, it can be advantageous to feed AC-power to the distribution grid. For an evaluation about these alternatives many parameters have to be accounted for, since AC systems usually perform less efficient, but are cheaper than DC-systems. They often were found to be more reliable also.
Such solutions (utilising still somewhat higher installed power) can deliver the energy needed to power a remote settlement or some small enterprise. Such units can be obtained readily from the market, even if in most cases a more detailed design is suggested. Especially the experience with systems serving more than one family or various purposes is blurred: "Community owned" systems frequently are less reliable due to excess use of energy or due to neglected maintenance.

2.2 Power Systems for Communication, Education and Business

Powering telecommunication systems by PV-conversion is an issue of increasing importance for regions with non-sufficient grid infrastructure. Similar systems are common also for traffic guidance (lighthouses; buoys), public addressing systems, and for communal TV-sets, which preferably provide tutorial services (lessons on TV, etc.). The flexibility of PV-systems facilitates the adaptation of the various components to fit nearly every purpose. The installed power for such appliances lies between about 700 Watts to some kilowatts.
So far high power industrial or commercial applications using solar conversion to electricity are rather scarce – in comparison -, notwithstanding such prominent examples as cathodic protection of steel structures (e.g.: pipelines) or the illumination of road tunnels. The latter application is a quite favourable option, since no batteries are required. The same holds for day lighting concepts in office buildings.

2.3 Air Conditioning, Heating and Cooling

The use of solar heat for hot water preparation is standard in many Mediterranean and Southern European countries. The technology is mature and can easily be installed. In hot climates still more advantages exist than for similar applications in moderate climates. Nevertheless, the utilisation is not widespread. One dominant reason for that it is not common practise of people to use heated water for sanitary purposes. Another decisive reason are the high expenditures needed for such devices – as compared to the well-known heaters using fossil fuels (e.g.: LPG) for household and agricultural use. Since the conventional energy

carriers (gas or Kerosene) often are subsidised, solar appliances need really be cheap to become economically competitive.
A rather new approach is the use of solar heat as energy source for air conditioning. The method of choice for this is absorption cooling. Promising results have been reported from tests with such equipment, even if the approach is not cost effective so far, especially for arid regions a very practical and cheap solution alternative is marketed: the so-called “Desert Cooler”, which is applying the evaporation of water to reduce the air temperature – adding the effect of increased humidity. Such devices directly driven by a PV-array (no batteries needed)were found to be economic and very efficient. On the other hand the method may have some disadvantages, if regular maintenance and specific care with regard to the water circuit (fouling, bacteria growth) is disregarded.

2.4 Electricity Storage, Hybrid Systems, and Back-up Concepts

Solar radiation being subject to stochastic fluctuations battery storage is often necessary to smoothen the energy output of solar electric systems. Accumulators can warrant permanent service and provide electric energy even during the evening hours.
Common battery sets are designed for the energy demand of 1½ to 3 days, larger battery capacities not only become quite expensive, also problems with regular cycling may arise with very large storage systems connected to somewhat less powerful solar arrays. The conception of adequate charging strategies then may become difficult.
Presently, lead-acid batteries in different kinds represent the state-of-the-art for such storage concepts, for small applications other concepts are in use also, Ni-Cd or Ni-MH being the preferred alternatives.
Another strategy to cope with the unreliable nature of R.E. resources and the demand is to combine different energy sources. Various propositions for the so called hybrid concepts are viable – some of them relying on fossil back-up, other ones combining solar and biomass use, others operating in combination with hydro-based plants.
Even if a hybrid energy source will not make batteries obsolete, its introduction is facilitating the conditions for the battery buffer, anyway. In many cases – then - quite small batteries will be sufficient – only bridging the period until the back-up generator is started.

3 Solar Cookers, solar Food and Crop Processing, and solar Refrigeration

3.1 Cookers and Food Preparation

Various methods have been proposed for solar cookers. An overview of different concepts is given in the **Figures 3 and 4**. Depending on the purpose and the projected demand “direct” solar cookers (with only very low sunlight concentration factors – if at all) and systems applying concentrated radiation are common. Any of theses devices yield fairly good results and offer a sensible opportunity to save firewood. Nevertheless - and despite of lavish efforts to disseminate knowledge and practical experience – the potential is still not exploited adequately.
All concepts for solar cooking have their benefits and disadvantages: Simple “boxes” are easy to build and to operate, but the meals have to be prepared during day-time hours, since heat storage is not viable. Given that, such devices require changes in peoples’ way of life, which impedes the public acceptance. Cookers with energy storage (e.g. with a combined oil and stone storage, Fig. 3) can be used after sunset, when traditionally the cooking is done. On the other hand, such cookers are quite costly – and the thermal oil used is environmentally risky, if

spoiled. When cleaning is not done carefully, such cookers with an integrated pot might even lead to hygienic problems.
For food preparation in larger quantities (communities; hospitals, schools, etc.) and for other purposes (for instance for baking bread), cooking devices with concentrating mirrors are common. Different designs from the shelf can be adapted to consumers' routines. In combination with a cavity oven parabolic dish concepts boast heat storage capabilities. They include the favourable characteristics of reaching high temperatures and to allow an extension of their use in the evening.
The stipulation that concentrating technologies must perform sun-tracking (all time keeping the focus on "target" – to concentrate the radiation impinges on the cooking pot or oven) requires an adjustable supporting structure and a device for automatic tracking (usually weight- or spring-loaded mechanisms). This makes the system rather complex. Moreover, since concentrated solar radiation can cause overheating, permanent surveillance of cookers is pretty important, which may necessitate permanent surveillance.

When ever cookers were found to be quite practicable for food processing (and even – in larger units – for sterilisation, pasteurisation of vegetables or fruits as well as cleaning of cans or bottles), an adequate solar energy input during the day is a necessary condition for their use.
If stable conditions cannot be warranted, the question of any "back-up" by other means is indispensable. This is of specific importance, when food processing is done, intended to fight losses caused by rotting or wasting away of produce.
From similar devices serving various process heat applications (up to high temperature processes) the combined (hybrid) use of different heat sources is a common practise. The preferred – then - technology is based on gas fired heaters (which allow to apply quite simple controls). In the case of solar cookers biogas offers a good opportunity, since this rely on a totally "renewable" energy system.

3.2 Drying of Agricultural Products

According to the various agricultural products many different methods have been developed for a conservation by drying. **Figure 5** shows some examples using solar radiation as the only energy source. If the product-specific drying cycles and conditions are granted by adequate design, excellent results and a very appropriate product quality were reported from such efforts.
Utilising similar concepts as mentioned above the combination of conventional energy resources (fossil fuels or biomass) and solar contributions allows switching over to auxiliary heating in times of weak irradiance. Then, at least a significant fuel-saving effect is reached in comparison to conventional drying processes.
Whatever type of equipment is used, local manufacturing is an important precondition for a successful application! This is the best way to keep costs low and to facilitate maintenance.

3.3 Product Conservation by Cooling

Solar powered coolers to refrigerate vaccines during transport and storage present an established procedure. The method is mature, even if mostly confined to rather small units.
There is also a market demand for larger solar coolers for food, potions, and other goods. Such cooling boxes usually embrace electrically powered Organic-Rankine-Cycles (ORC), routinely supported by batteries to make the system independent from sunshine hours.
The use of highly economical units is an important feature of such devices to warrant adequate energy savings: The casing of the cold space must be designed for very low heat losses, the driving motor and the cooling cycle components must be very efficient, and the design of the

overall system and of the auxiliary devices has to be done with respect to high ambient temperatures and sometimes tough environmental conditions.
A rather recent alternative to the ORC-process for tropical conditions is absorption cooling. Even if applicable in small units, too, the absorption process is best suited for larger demand, e.g. cold stores, and for air conditioning. Solar process heat in a temperature range of 90^{o} to 130^{o}C is appropriate as the driving force. The technology is well established, but the production numbers of such units are rather small, consequently the costs are still high. So people in regions, where the demand for such cooling devices is urgent, are reluctant to invest in such equipment.
Thermo-electric devices (based on the Peltier-effect) are more or less of historic interest. Since these elements have a quite low efficiency they are practicable in very small units only and not suggestible for permanent use.
For somewhat larger demand successful trials have been made with Stirling units in an "inverse" thermodynamic cycle. Good efficiencies could be demonstrated, but so far the costs of such devices are quite high.

4 R.E. systems for water pumping and water treatment

Renewable energy is a common power source for water pumping; and increasing importance can be allocated to procedures, which either allow a more efficient use of limited water resources (for instance: optimal use of water for irrigation purposes), or which can convert wastewater or saline water resources to meet the terms of water for drinking or other purposes. **Figure 6** illustrates that the global water situation is already tense – and the prospects for the future are still more severe.
In many countries in the "solar belt" nearly all accessible water resources are already exploited, leaving no reserves for the projected population growth. A similar situation might be expected for some industrialised regions, but here a trend extrapolation does not indicate a comparable urgency, since only in the developing countries nearly all water resources are needed for life supporting purposes
Moreover, in many tropical and arid territories a direct relationship exists between water resources and crop production. The curves compiled in **Figure 7** indicate the future trends, underlining that any means adequate to enlarge the utilisation schemes for water (e.g. by a reuse or recycling) are valuable contributions to benefit human beings.

4.1 Water pumps

For water pumping in remote areas wind and solar power are common sources. In particular wind pumping is a traditional method, where fair wind conditions prevail.
The use of alternative energies based on solar radiation is a rather recent task. Eventually, PV-water pumping turned into an established and more and more attractive procedure. Meanwhile, for remote locations such systems are competitive to Diesel pumps, even if so far the viability in economic terms is restricted to low power applications.
The current design of a pv pumping system proposes a directly driven pumping unit – operating without storage batteries. If necessary, water tanks on an elevated level are provided to warrant an all-day water delivery. **Figure 8** shows a schematic of a PV- pumping system, indicating the dominant parameters defining its lay-out and hydraulic performance. The provision of a water storage is optional, but in most cases very advantageous.
Many producers offer various units and types as well with regard to pumps as to motors: Centrifugal pumps with AC motors present sort of standard, displacement pumps and DC motors also being available, but usually applied in "non-conventional" applications –

despite of the fact that under many circumstances DC systems perform better. Nevertheless, cost advantages exist for AC motors, and therefore the market is dominated by such types.

Despite of the fact that pv pumping for drinking water supply is a common practice, this method is of much less importance so far in field irrigation concepts. Tests with such systems show that the design and adaptation of the pumping equipment and the distribution network is quite a complex task, not only with respect to adequate measures to minimise pressure losses, but also concerning an uniform water distribution throughout the field. This becomes especially demanding on slightly inclined surfaces.
Elevated water tanks and / or electronic control devices seem adequate to cope with the difficulties, but this also – together with the necessarily rather sophisticated distribution devices (drip or sprinkler irrigation being viable) - contributes to pretty high costs of such systems.

4.2 Water purification, sterilisation, and decontamination

Estimates indicate that more than one third of the global population has no access to clean and unpolluted drinking water. So, methods for water treatment are urgently needed, and various proposals have been made to handle that issue properly.
Not all known procedures are suited for third world applications: the units need be simple, reliable, and should perform without or with a minimum of additives. Nevertheless, many concepts have been proven to be adequate. A few examples may illustrate the situation:
A very popular method for sterilisation of otherwise "clean" water is the treatment by UV-light (**Figure 9**). The procedure is safe and fast, but it is ineffective, if the water is muddy.
In contrary, heating of water beyond the temperature levels sufficient to destroy any micro-organisms (pasteurising) is very effective - even if the raw water is cloudy or abrasive particles. The disadvantage of such a thermal procedure (**Figure 10)** is a moderate risk of re-contamination, if emptying and refilling of the reactor is not done very carefully. To facilitate this task, some provisions (including also safety valves, etc.) have to be made.
A proper treatment against various other pollutants is filtering, for instance applying a combination of a fine mesh filter and an activated carbon cartridge.
For high concentrations of hydrocarbons in water high temperature processes have been tested, utilising concentrated radiation to decompose the toxins (**Figure 11**). Depending on the chemical reactions it is common to use additives or catalysts to accelerate the processes.

The examples presented (as any method envisaged) need be considered with respect to the raw water quality, the degree of pollution, and other factors possibly influencing the performance of the procedures applied. So, a rather careful examination of the local conditions is necessary prior to any decision making.

4.3 Desalination

Similar arguments apply to water desalination. The parameters influencing the choice of proper methods are: The actual raw water salinity, the desired product quality, the daily delivery rate (amount of water needed), and – in remote areas possibly of very high importance – the extraction rate. Where there is scarcity of water, a high extraction rate can compensate for much higher costs, to avoid running down the source and also circumventing problems with the refusal of the brine.
Technologies for water desalination comprise traditional ones – and some quite sophisticated processes: The long-established solar still (**Figure 12**) and the derivative multistage stills (**Figure 13**) use the solar heat directly. The humidification principle based on circulating air (**Figure 14**) also belongs to these rather "simple" procedures.

Other desalination units were proposed by converting techniques from industrialised processes to the specifications of solar powering. Any of these methods (multi-effect distillation, vapour compression, electro-dialysis and reverse osmosis (R.O.)) can be powered by solar energy, but only the last ones are of a certain technical significance.
The main reason that a combination of thermal desalination processes with solar conversion is not common up to now lies in the fact that these methods are not so well suited to an operation under variable conditions, and that there is a limiting size parameter, reducing the applicability in small units. Moreover, the temperatures required for distillation processes are rather low: to avoid scaling the highest temperature in the process must not exceed 120°C. This suggests a combination of a distillation process with a power plant – which represents the standard configuration of large scale desalination systems.
On the other hand electrically or mechanically driven desalination processes have been proven to be applicable in combination with solar powering concepts, the preferred method being the reverse osmosis.
Anyway, high energy demand and necessary expenditures for desalination equipment necessitate a careful evaluation in any case, not only with respect to the availability of energy sources and environmental aspects. The schematic of a solar R.O. process shown in **Figure 15** illustrates that even this method is not at all simple, and it becomes still more sophisticated, if for reasons of energy savings an expansion device is introduced in the brine outlet duct.
In comparison the energy demand and the specific costs for water treatment and decontamination are definitely lower than for desalination processes, which illustrates the advantages of reusing available water resources. In **Table 2** the relevant energy and cost data for the desalination processes and for some selected purification methods are compiled. For R.O. the table lists different figures, showing the dependency from the salt content.

Table 2: Specific Energy Consumption and Cost Parameters for selected Water Treatment Processes

Process	Method	Specif. Energy Consumption		Costs [US-$]	Remark
Desalination	Distillation	>60 kWh/m³	Process Heat	no data for "solar" plants	
		2 – 5 kWh/m³	El. (mech.) Energy		
	Rev. Osmosis	8 – 20 kWh/m³	Electr./mech.Energy	12,- $/m³	Seawater/
		6 – 12 kWh/m³		10,- $/m³	brackish W.
	Solar Still	~700 kWh/m³	Solar Radiation	< 6,- $/m³	
Purification/ Sterilisation	UV-Light Appl.	0,8 – 1,5 kWh/m³	Electricity	< 0,5 $/m³	
	Pasteurisation	> 65 kWh/m³	Process Heat	< 1,5 $/m³	

5 Economic Considerations about Renewable Energy Utilisation

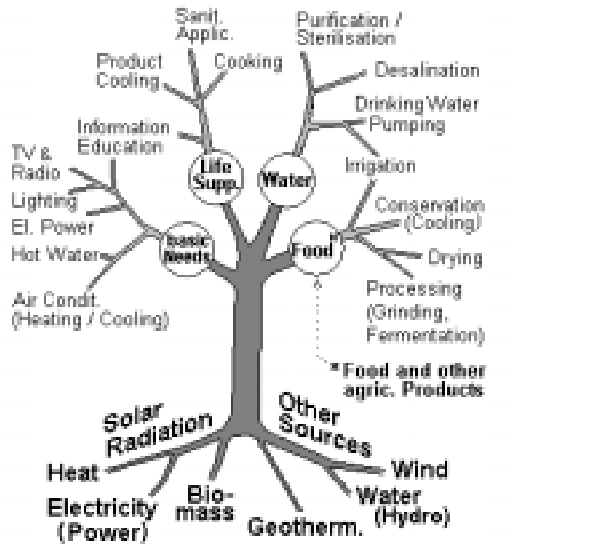
High expenditures required for the solar equipment present the main obstacles for a more widespread application of R.E. in remote regions or for a accelerated dissemination. This is true despite of the fact that many examples show that such techniques are competitive to fossil fuel use. Energetic and environmental reasons also support the introduction of R.E. sources.
The situation is changing thanks to the awareness of some benefits allocable to R.E. use. Arguments of comfort, reliability, and use of "local" resources contribute to a shift in the opinion of politicy makers and users.
Economic analysis tasks performed with Solar Home Systems and Water Pumps underline that such concepts offer sound solutions, at least where the energetic demand is small.
In the cases compiled in **Table 3** the competing solutions are the solar powered systems on the one hand and Diesel or Kerosene driven units on the other hand. The comparison does not quote for possible differences in performance (which may not be quite large, anyway) and with regard to comfort and reliability, even if those features may be of importance for the

customers. As can be seen, solar solutions are superior at least as long as small systems are regarded.
In countries, where fossil fuels for agricultural and domestic use are subsidised, the figures presented in the table were influenced accordingly. Then, only similar subsidies for the solar components could maintain equilibrium.

Table 3: Cost comparison for Lighting and Water Pumping Systems

Objective	Alternatives	Typical Rating	Specific Expenditures	
Lighting	PV vs. Kerosene Lamps	30 W_{PEAK}; 8 – 11 W lamps	8 – 12 $/month ~ 10 $/month	Kerosene Photovoltaic
Water Pumps	PV-(electric) versus Internal Combust. Engine	~1 kW	0,45 $/m³ <0,3 $/m³	Diesel Pump PV Pump
		~2 kW	0,25 $/m³ 0,2 $/m³	Diesel Pump PV Pump
		~4 kW	<0,2 $/m³ <0,2 $/m³	Diesel Pump PV Pump

Still more difficult is the situation in the field of water desalination. Wind powered Osmosis is proven to be cost-effective in many coastal regions, solar powering of such plants is – for the time being – only viable, if very favourable water conditions (and low salinity) prevail.
Nevertheless, with a widespread dissemination of R.E. appliances also the confidence of the people in the new technologies will grow, preparing the field for further utilisation.



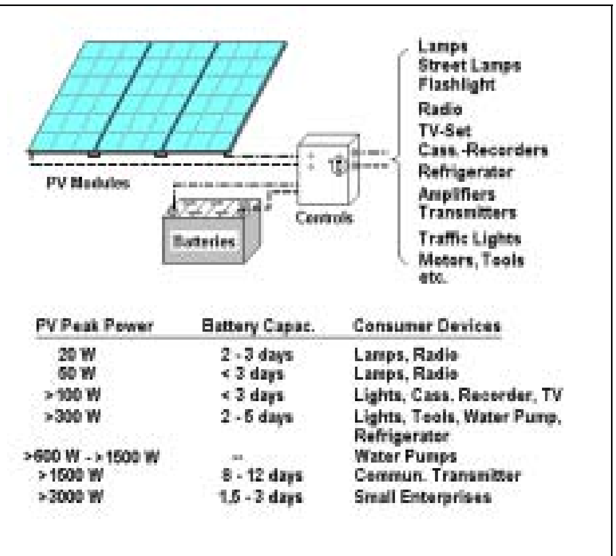
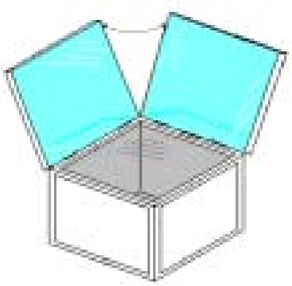
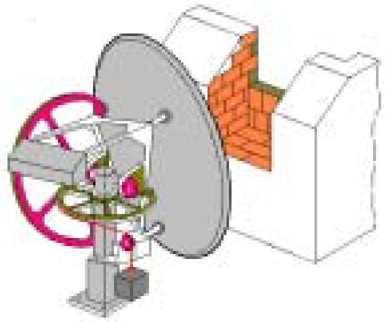
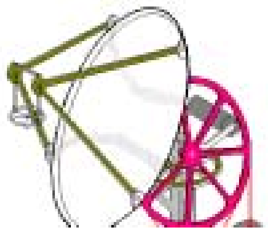


Figure 1: Renewable Energy Sources and Appliances for Remote Regions

Figure 2: Stand-alone PV System Schematic – Main components and ratings of commerc. systems







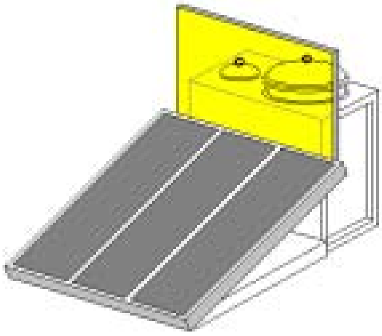


Figure 3: Solar Cookers: Box Concept (with mirrors as boosters) and Thermal Oil Heat Collector (usually with oil / stone storage)

Figure 4: Concentrating Devices for cooking Purposes (Parabol. Dishes)

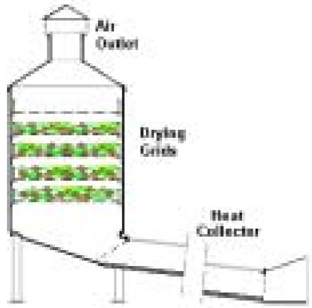
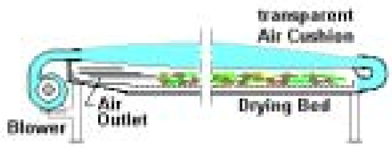


Figure 5: Examples of solar Dryers: Stacked grids (left) and horizontal bed dryer with air-filled cushion (below)



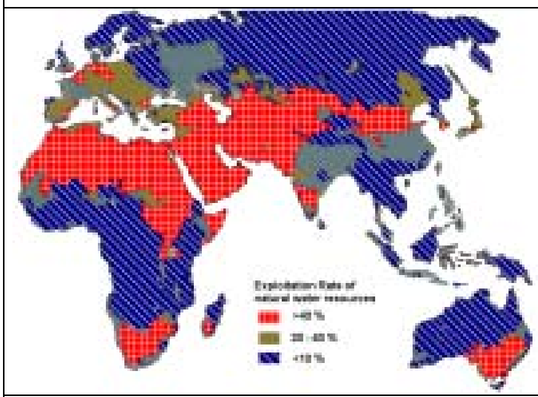


Figure 6: Exploitation Rate of Global Water Resources

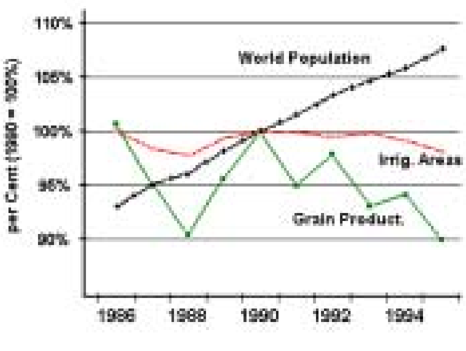


Figure 7: Global Population Trend, World Grain Production and irrigated Land Area

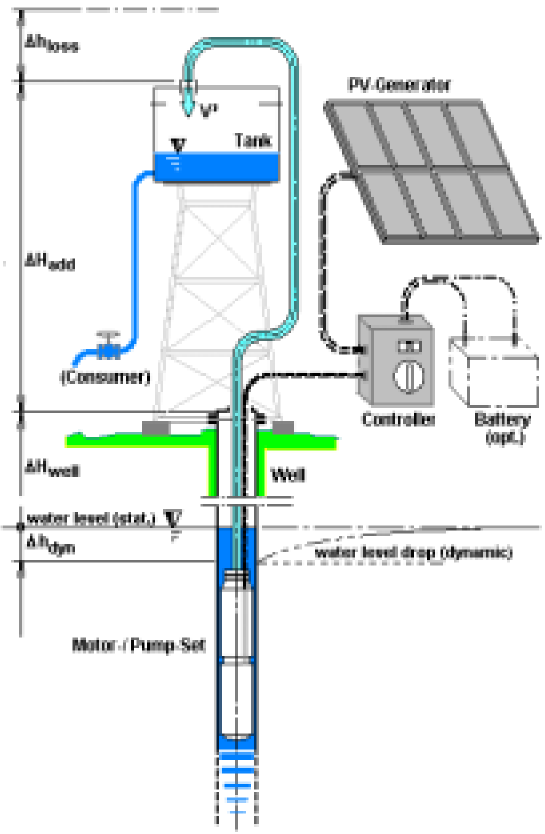


Figure 8: PV pumping system schematic

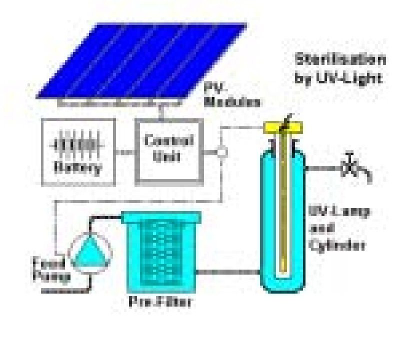


Figure 9: Water Sterilisation with a UV-light Source

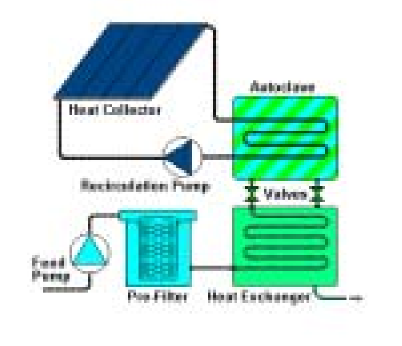


Figure 10: Water Pasteurisation with solar Process Heat

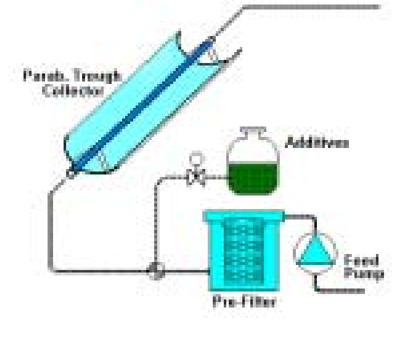


Figure 11: Water Treatment with a parabol. Collector

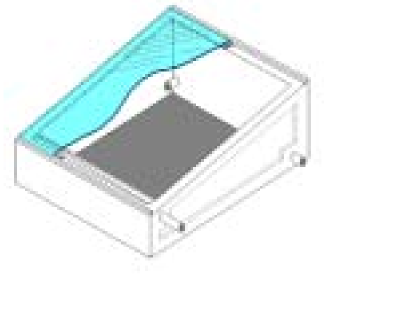


Figure 12 : Solar Still

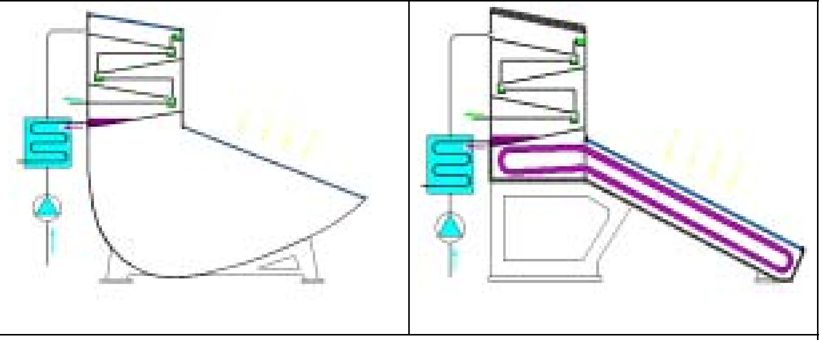


Figure 13: Multistage Stills with direct and indirect solar Heating

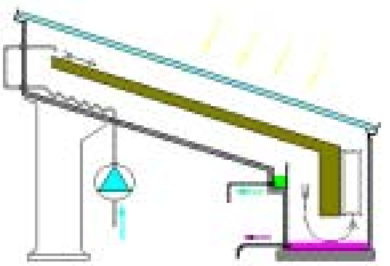


Figure 14: Humidification (air circulation) concept

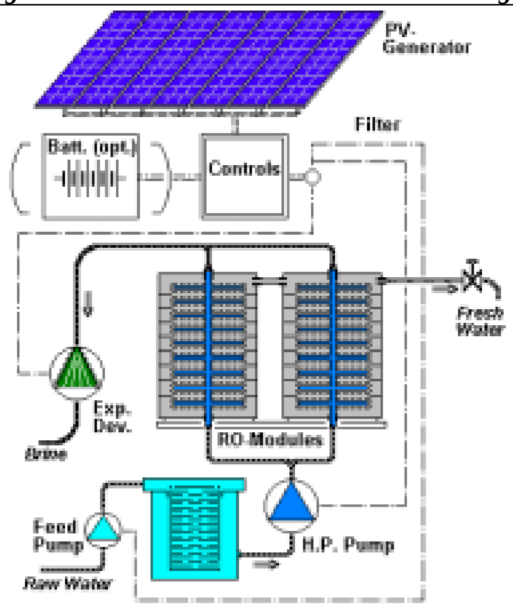


Figure 15: Solar Reverse Osmosis Process