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"Prospects for Photovoltaics: Commercialization, Mass Production and Application for Development"

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The Role of R&D in the Development of a PV Capacity: a Critical Appraisal

Ivan Chambouleyron

Science and Society

At present, economic growth is considered a necessary condition for development. In industrialised as well as in less developed countries the economic growth is associated, correctly or not, with technological innovation. This premise demands the establishment of R&D systems aiming at the organisation and optimisation of the available human and economic resources.

Most less developed countries have been characterised as dual societies composed of a modern and a traditional sector, the per capita income and the cultural habits and patterns of consumption being vastly different between the two sectors. The wealthy sector of the population tends to adopt the lifestyle and the corresponding technical innovations of advanced countries. On the contrary, the poor sector stays largely outside of the benefits offered by modern science and technology. It has to be noted that, in the past decade, the vast expansion and universalisation of mass communications have started to alter the cultural habits of the poor sector without any concomitant improvement of its material situation.

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The R&D systems of less developed countries reflect this dichotomy. The productive sector resulting from these more or less successful accelerated industrialization processes uses, in general, foreign technology. Consequently, the demand on the local R&D system is relatively small. This general characterisation may be of variable applicability depending on the country and specific research area being considered.

This is a typical vicious circle situation where the lack of qualified scientists and engineers hinders the possibility of establishing independent industries. In turn, the prevailing industrial pattern does not require highly qualified people.

Physics, Electronics and Development

In the last decades, and particularly with the advent of space flights, microelectronics and computers, it became evident that physics and solid state electronics play a key role in technological innovation. In advanced countries, the need for talented physicists and engineers grew at an exponential rate, a tendency not followed in less developed regions. It is not meant here that the existence of trained scientists may foster, by itself, a technological revolution in less developed countries. Although there is not a simple one-way flow from fundamental research and advanced engineering to industrialisation and commercialisation of new products, it is today widely accepted that R&D activities in physics should be strengthened in the developing world. This is so because it appears that such strengthening is a necessary condition to support, or to give birth, to advanced technological industrial projects. Two questions are in order: what should be done, and how to do it?

Taking into account the great diversity of the developing world, it is impossible to cope with such a general and complex problem in a unique and simple way. Many times the problem addresses aspects from physics and technology, such as cultural traditions, education systems, available resources, etc., which prevent a unified presentation.

R&D in Solid State Electronics: the Latin American Region

The above-mentioned difficulties induces us to analyse the case of the R&D efforts made in the Latin American region in developing an independent capacity in the area of microelectronics. From it, it may be possible to extract some conclusions applicable to other regions of the Third World, or to the establishment of a research capacity in the field of photovoltaics. Solid state electronics supports the development of an independent industrial capability in the fields of computing, consumer and industrial electronics, and communications, which are considered essential for a modern and sustained development.

The development of an independent capability in electronic technology requires the existence of R&D laboratories able to proceed through the following steps: a) understanding the physics behind technology, b) local reproduction of technology and, c) innovation (if possible). In order to produce some significant results, the experimental facilities required in laboratories aimed at R&D in semiconductor technology are not extremely expensive. This being the case one is led to ask why the subject has not been developed so far, for it is known that the contribution of the Latin American region in the field of solid state electronics is very small, either at a laboratory, or in an industrial level.

Before going into details, let me clearly state a couple of points. First, the following considerations have, necessarily, a general character. In that sense, they may not do justice to some successful laboratories or industries, to whom I apologise in advance. Second, they correspond only to my personal experience. This necessarily means a partial understanding. For the sake of completeness let me also say that I have been working in the field of semiconductor materials and devices for the last 30 years, 10 of them in Europe and 20 years in the most industrialised Latin American countries: Argentina, Mexico and, since 1979, in Brazil.

Besides the common cliché saying that the lack of large funds prevented the appearance of sound R&D activities in the region, other reasons should be considered. They are, in my opinion, fundamental in explaining the "relative" failure of most research laboratories. The list of important constraints preventing the successful development of sound R&D activities in the majority of Latin American countries includes:

a) political instabilities disrupting the work of successful research teams;
b) lack of long-term support;
c) establishment of R&D projects without clear objectives;
d) research teams lacking the necessary scientific background or experience to develop advanced technology;
e) absence of scientific leadership and methodology;

f) corrupt R&D systems supporting incompetent groups because of political or spurious reasons, etc.

During the last ten years, our Laboratory of Photovoltaic Conversion established an active scientific collaboration with research laboratories of the Latin American region. The subject field was the science and technology of amorphous semiconductor materials and photovoltaic devices. This experience allowed us to gain a deeper understanding of the nature of the problems which may limit regional research efforts. The collaboration included the exchange of researchers and students, the exchange of samples and results of characterisation, and the construction of small equipment.

The main conclusions of the South-South scientific collaboration follow:

1) Within the framework of this experience, funding has seldom been the main limitation for international cooperation. Appropriate support for scientific exchange (travel fare and sojourn) was obtained from national and international financing agencies.
2) Most Latin American laboratories, and particularly those involved in the collaboration referred to, possessed enough experimental facilities to deposit amorphous films and to proceed to their basic optoelectronic characterisation. Let us remember that the operations only require inexpensive equipment such as: vacuum systems, some special gases, monochromators and light sources, current and voltage sources, DMMs, substrate holders with controlled temperature, etc. In many cases, however, a small out-put/input ratio was detected, in particular with respect to experimental results. We believe this to be due to the lack of an appropriate methodology to deal with research problems and to the absence of clearly established research objectives.
3) Our experience indicates that the most fundamental problem is human resources, in particular scientific leadership. A certain difficulty in performing continuous and long efforts on the same subject has been detected, as well as the dangerous tendency to shift to "à la mode" subjects, such as high Tc superconductors, cold fusion, etc.
4) A very positive aspect of the collaboration is that young colleagues, coming from less advanced laboratories, perform research at Unicamp using experimental facilities similar to those of their home countries. This experience makes clear to them that research work does not necessarily imply the availability of the most modern and sophisticated equipment. We find it useful to stress the importance of this scientific training under conditions not far from those prevailing in third world country laboratories.

In summary, the overall balance of this collaborative work with Argentina, Colombia, Mexico, Venezuela, Chile and Peru, was highly positive though a lot of room for improvement exists. The training of human resources appears to be of utmost relevance, in particular the scientific training of senior researchers.

International Cooperation

Past experience shows that the human resource training policy consisting of sending numerous PhD students to laboratories of the first world possesses both advantages and drawbacks. The benefits are obvious, in the sense that advanced training and good scientific formation are guaranteed through the acquaintance with sophisticated equipment and the permanent interaction with first class scientists.

On the drawback side of the matter, there are several considerations to be made. There is, of course, the brain-drain problem associated with this policy, for it is well known that a fraction of the trainees will never return to their home countries. Besides this loss of qualified people, it is not obvious that the specific training received by third world students corresponds to the formation required to work in his/her own land. The normal situation is the incorporation of the newly arrived to an already existing task force. Normally, the acceptor teams have projects being financed to attain specific research objectives at a scientific level in accordance with the host laboratory expertise. For an inexperienced trainee this situation may, sometimes, contribute to disqualify the kind of research currently done in his home country, which in general possesses different objectives and is performed at a lower level of sophistication. It has been observed that in many cases the trainees, once back in their own country, tend to reproduce the research projects in which they were involved in the advanced laboratory. These efforts made in a completely different context are seldom successful.

On the other hand, and we believe this to be a very important point, the third world trainees will not acquire the expertise necessary to perform scientific research with the materials and laboratory facilities normally available in less developed countries; in other words, he does not learn to optimise the existing equipment in the realisation of sound projects. It is a common experience for international consultants visiting laboratories of less developed countries to find that the amount of research results is far inferior to the possibilities offered by the existing experimental facilities. Frequently, local researchers tend to attribute this low productivity to the lack of the most modern or sophisticated equipment, a kind of a spurious interpretation of a human resource problem.

Another way of promoting the development of R&D in experimental physics and advanced technology is by the allocation of important loans to finance the purchase of scientific equipment. These large projects are normally negotiated between governments and banks. The relative success they may have depends largely on the specific programme or country. Some of them are successful, some are not. It is not the intention here to analyse this particular way of scientific cooperation. In passing, we note that sometimes the use of the loan is far from optimised, in the sense that R&D systems not having the necessary expertise may purchase a lot of equipment of little use in the country. It has been noted that these large bank loans are, many times, a disguised subsidy to first world industry.

International Cooperation in Photovoltaics R&D: the Likely Role of the First World

The above considerations lead us to think that, in order to promote a sound photovoltaic R&D programme that optimises the resources at hand, an effort to devise new cooperation schemes should be made. We bring to the present debate the following ideas:

A) Productive and mature research groups, as well as promising young researchers, should be detected in third world countries wherever existent. This is a difficult task, but not an impossible one. The help of some local specialists is essential. Care has to be taken to avoid the use of official channels only which, in most cases, will proceed to erroneous identifications. These research teams should receive help and encouragement in the form of grants, travel to conferences, scholarships for their students, small material, updated bibliography, etc. Scientific visits and short courses by first world specialists may be programmed at regular intervals. This scheme will strengthen the research capability of efficient laboratories, which in turn may become reference places for surrounding institutions or research groups. In a few years reference laboratories or centres of excellence, disseminated in the different regions of the third world, would play a vital role in the spread of scientific knowledge and photovoltaic technology, and in the training of local people. The philosophy behind the proposal is that the most effective training is the local one. This is for two reasons.

The first is that young trainees from the region discover that experimental research in physics and solid state electronics can be made in laboratories such as those existing in their own institution. They also learn how to solve daily problems, to fix equipment, to work with the materials and equipment at hand, to deal with the bureaucracy, etc.

The second reason is more of a psychological nature. It is our own experience that many talented people from less developed countries do not endure a long sojourn in an industrialised country. It is not only a problem of homesickness. Completely different cultural traditions may be at the base of this discomfort which may threaten the training programme. This handicap must be added to the difficulties related to training programmes as previously mentioned. In summary, high quality research done in good laboratories of the third world should receive special support.

Based on the premise that cooperation efforts should be directed to places where actual research is being done, the existence of third world centres of bureaucratic nature, having as a fundamental task the distribution of money and the organisation of meetings, should be discouraged. These costly institutions are ineffective in promoting true research activities.

B) A kind of partnership programme should be established addressing true cooperative work between advanced and less advanced research groups. One possibility is, for instance, to associate productive research teams or centres of excellence of the third world with some of the first world programmes involving photovoltaics. By association, it is not meant here just to subcontract part of the task. On the contrary, the idea is also to share some expertise with the less advanced and to allocate special funds to cover small material, spare parts, and other small items of difficult reach in the third world, for it is well known that many times, in less advanced countries, it is possible to buy relatively expensive equipment but it is impossible to put it into work once a small piece or consumable is missing.

Scholarships intended to cover specific needs of the young physicists and engineers of the selected laboratories, should be included. They must be awarded on the basis of clearly established research programmes: that is, they should address training that corresponds to the requirements of actual research. Scholarships and travel aid for South-South cooperation is also an essential part of the proposal. Training people within the region is much less expensive and, in some cases more productive, than to send every researcher to a laboratory of the first world. Besides the already-mentioned benefits of working in a similar laboratory, this opens a new possibility for people not normally included in the current exchange programmes. Technicians, undergraduates and people not knowing foreign languages, are among them. Some experience in this direction is available in the International Science Programme, Uppsala University, Sweden. Our experience indicates that this exchange system is the one producing the highest output/input ratio.

C) As a complement to the centres of excellence in third world countries, of the kind described above, institutions such as the International Centre for Theoretical Physics (ICTP), Trieste, Italy, should be created in advanced countries. Since 1977 the ICTP has been organising workshops on Renewable Energy Sources, Modelling and Management of Energy, Environment Conscious Design and the like, both in English and French. The activity has been explicitly meant for participants from less developed countries who have found, in the ICTP, an appropriate structure to learn the most recent developments, as well as grasping future perspectives, presenting their own projects and discussing collaboration schemes. The ICTP constitutes a good example of fruitful interaction between Europe and the third world and it might be timely to think about other places of the kind having some degree of specialisation. The recent proposal to establish an International Centre for Science and Technology in Trieste goes in the right direction.

Finally, how should we cope with the problem in places where almost nothing exists? These cases deserve special attention and South-South cooperation is probably the best starting point. There is not a general recipe because the situations may be very different. The assistance of some specialists, from developed and less developed countries, will be necessary in order to establish some sound starting programmes.

Conclusions

This presentation considers the likely impact that scientific research produces on economic growth and development. It has been found that the existence of mature and productive research teams in the field of physical science and technology are a necessary but not a sufficient, condition for the sustained development of advanced technologies. One of the main causes limiting the appearance of such groups and laboratories in third world countries is the absence of scientific leadership. Some ways of alleviating this chronic deficit of well-trained human resources are discussed. Among them, the importance of supporting productive research groups already existing in third world countries is stressed. These advanced groups should play a key role in promoting South-South collaborative work and training in experimental physics and advanced technology. A complementary action in the first world should include the establishment of international centres for advanced training.

Integrated Policy in Environment and Energy Development

Ivan Chambouleyron

Energy and Society

Energy is a fundamental input in the development of any human society. However, the amount of energy required per capita to foster or to maintain the development depends largely on the development stage, the local resources, the social and economic model chosen by the country, and other factors. Today, most countries rely on local or imported fossil fuel to supply a large fraction of their commercial energy needs, although it became clear after the oil crisis that supply disruption, either due to political reasons or simply to source exhaustion, was a likely situation to happen during the next decades. Until very recently, many energy planners of industrialised countries believed in a successive replacement of fossil energy sources by nuclear, and then nuclear by renewable resources. The accidents of Three Mile Island and Chernobyl (in particular) showed however, that the environmental risks of nuclear power are potentially catastrophic for mankind. The release of radioactivity from nuclear accidents in power stations or other parts of the nuclear fuel cycle may induce vast social costs which are not yet fully quantified. As a consequence, the population of most advanced countries today manifests a strong opposition to nuclear electricity generation. Vast reserves of coal were once considered a viable alternative after oil exhaustion. Nevertheless, in many countries it is now recognised that the negative impacts of massive coal burning on the environment (mainly acid rain and liberation of CO_2 into the atmosphere) and human health are important enough to disqualify coal as a viable long term solution. It appears then that the era of renewable sources of energy has to be brought forward, even if at the moment oil prices are not particularly high.

What characterises the advanced societies is their enormous consumption of energy which is obtained at the expense of *capital energy* rather than *income energy*; i.e. fossil and nuclear fuels rather than renewable. Western Europe, the United States and Japan account for almost 80% of the world's oil imports. They stand opposite the exporting countries of the Middle East and the OPEC countries of Africa and Latin America, who together export 80% of the world's oil.

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The energy consumption corresponding to the various levels of development is represented in *Figure 1*. The consumption rate ranges from the minimum of 2000 kcal/day, supposed to be the energy content of primitive man's daily diet, up to around 200,000 kcal/day of the present per capita energy consumption of the citizens of the most advanced countries. *Figure 1* shows the energy consumption corresponding to different stages of development. Note that many regions of the World have nowadays an energy consumption level corresponding to low stages of human development. Moreover, most developing countries possess a highly uneven geographical distribution of per capita energy consumption, not apparent in the averages displayed in *Figure 1*. In nearly all Third World countries this uneven energy consumption derives from the existence of relatively large industrial (or urban) centres amid poor and backward regions. Although the problems existing in these poorer regions are not exclusively related to energy, it is a fact that rural areas in developing countries lack energy to a greater extent than urban centres. This energy deficiency not only refers to transportation, lighting and home comfort, but often takes on a calamitous aspect for millions of human beings who suffer from the lack of drinking water and food, illiteracy, diseases and isolation.

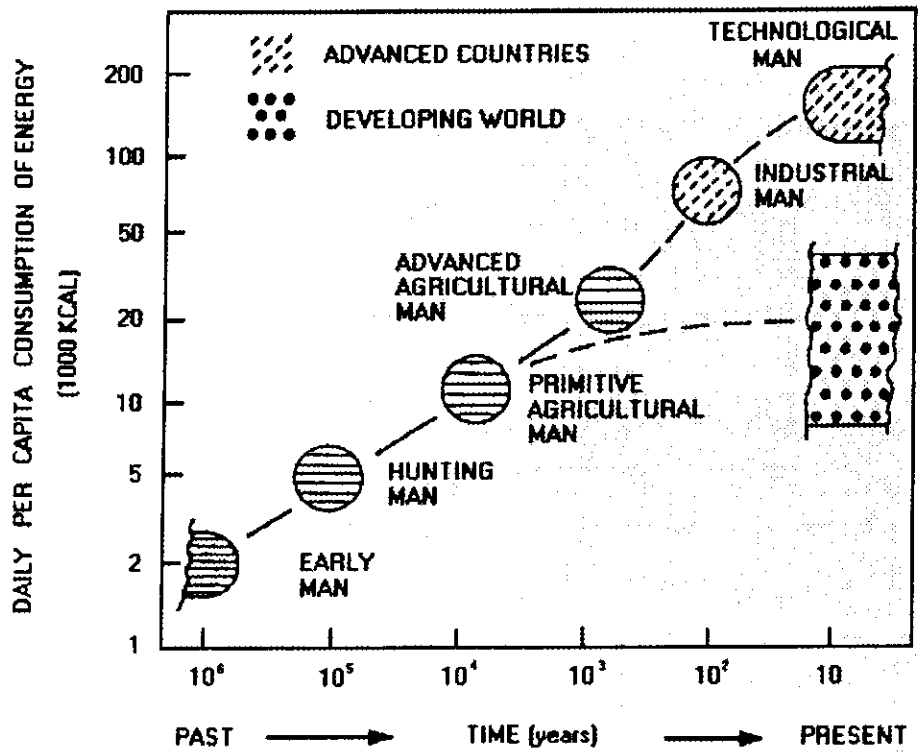
Let us also mention that many of the countries included in the dotted area of *Figure 1* which represents the developing world, are oil exporters, an indication that the availability of cheap energy is not a sufficient condition for development. Among other factors, a political will and sound schemes for social and economic changes are also necessary to foster development.

Economic and Political Aspects

It is at present universally recognised that solar electricity is an almost ideal energy source, with low maintenance costs and no negative environmental impacts. The question arises then as to why this energy generating technology is not widely used in all places where other conventional energy sources do not exist, or in cases where the energy sources at hand are environmentally risky. Let us analyse some aspects of the question and show that the answer involves governmental energy policy and planning, energy lobbies and developmental issues.

In a market economy, decisions on the allocation of resources are made considering the market prices which, according to theory, reflect all costs involved in production. This being the case, the market mechanisms will lead to a macroeconomic optimum in the use of resources. However, in the case of electricity generation by fossil and nuclear fuels, substantial costs of the production process are not reflected in the market prices because such costs are passed on to the whole society. These external or social costs may constitute a large fraction of the final price the society pays for electricity. It is important to note here that external costs refer not only to environmental damage but also to the depletion of nonrenewable resources. It is clear that the massive waste of fossil fuels today is made at the expense of future generations which will not have access to energy at such low prices. The depletion problem does not appear sufficiently in the present market energy prices.

In most countries, particularly in the Third World, large plants for electricity generation are state planned and owned. Up to now, the photovoltaic market, which is mostly decentralised, is essentially private. Electricity generation with fossil or nuclear fuels requires a smaller initial investment per installed kWatt capacity. The production costs, or direct costs, per unit energy output result from the invested capital, plus the costs of maintenance and fuel, which are distributed along the useful lifetime of the plant. In the case of photovoltaic electricity generation, either centralised or decentralised, there are no fuel costs and practically no maintenance during operation, but the initial investment is high. The



DAILY CONSUMPTION OF ENERGY PER CAPITA AS CALCULATED

FOR SIX STAGES OF HUMAN DEVELOPMENT:

Early man had only the energy of the food he ate.
The controlled use of fire by the hunting man adds some 5,000 kcal/day.
Primitive agriculture incorporates crop growing and animal energy.
The water mill and the windmill are incorporated in advanced agriculture (Europe, around 1400 AD).
Industrial man had the steam engine.
The technological man uses electricity and internal combustion engines.

The developing world is represented by the dotted area.

Figure 1. Energy consumption and stages of development.

comparison is still more unfavourable to PV when the social costs are not included in the final price of conventionally generated electricity.

Investments in electricity generation and/or distribution are planned taking into consideration, among other factors, the cost of the money offered by the national or international financing circuits. The amounts of money involved in the construction of large conventional energy plants and the negotiating power of the governments or the electric companies, result in loans at an interest rate much lower than that a private investor willing to install a photovoltaic system may obtain from a commercial bank. In other words, the cost of money is higher for small systems than for big central units. The impact of the different interest rate appears in what is called the actualisation rate, or the annualised cost of the investment. The actualisation rate is central for decision making. A high actualisation rate penalises the future at the expense of the present, in the sense that energy technologies requiring a large initial investment will not be chosen, even in the case of a long term benefit for the whole society. On the contrary, energy technologies requiring a lower initial investment will be favoured even if they are not beneficial in the long term.

The problem may be more severe in developing countries, depending on the relative scarcity of financial resources and inflation rate. For example, the financing capacity of Third World countries is generally small. As a consequence, interest rates tend to be higher than in advanced countries. Moreover, countries having a considerable inflation rate will penalise still further the energy systems requiring high initial investment. High inflation rates tend to make more attractive those investments giving a high return in short periods, because of the uncertainty which inflation projects on the future.

Besides the above economic considerations, there are political aspects involved in the absolute preference for centralised systems. A centralised energy system concentrates in the hands of the administration a great deal of political power. It is a well-known fact that electricity tariffs seldom reflect the true operational costs, in particular in areas or in economic activities being promoted. A typical example is the high subsidy normally going to rural electrification programmes. The availability (or not) of electricity at a special tariff may represent an important issue for a large fraction of the population, which may be subject to political constraints. Decentralised electricity generation, on the contrary, makes the user independent of political constraints, arbitrary tariffs, electricity shortage, etc.

In advanced countries, the funds for, and the research efforts on solar technologies are ridiculously small compared to those devoted to other less benign energy technologies. Examples: during the last decade a little over 100 million pounds sterling have been spent in the United Kingdom on the research and development of new and renewable energy technologies. This has to be compared with over 4 billion pounds on nuclear fission.

A similar situation occurred in the USA where, under the Reagan administration, the budget for solar research was considerably reduced. As shown in *Figure 2*, the comparison between the funds allocated to renewable technologies compared to those going to nuclear fission and fusion is still more unfavourable to the former. Let us note that the figure does not include nuclear research for defence purposes. This situation is reproduced in almost all highly industrialised countries. It is unfortunate to note that, as long as oil prices stay at a moderate level, research and development efforts necessary to make solar electricity a viable alternative are so modestly funded.

Including the Environment

The main favourable aspects of renewable sources of energy are related to the general recognition that they are environmentally benign. In terms of direct costs however, they range between half the price, for hydroelectricity, to nearly four times (photovoltaic) the current cost of fuel based systems. These costs, reflected by the market prices of the different energy technologies and the operation and maintenance costs, are referred to as direct costs. It is important to note that if indirect costs, also called social costs, such as those derived from the degradation of the environment or from the increased costs of the health care of the population are taken into consideration, the cost differences narrow considerably.

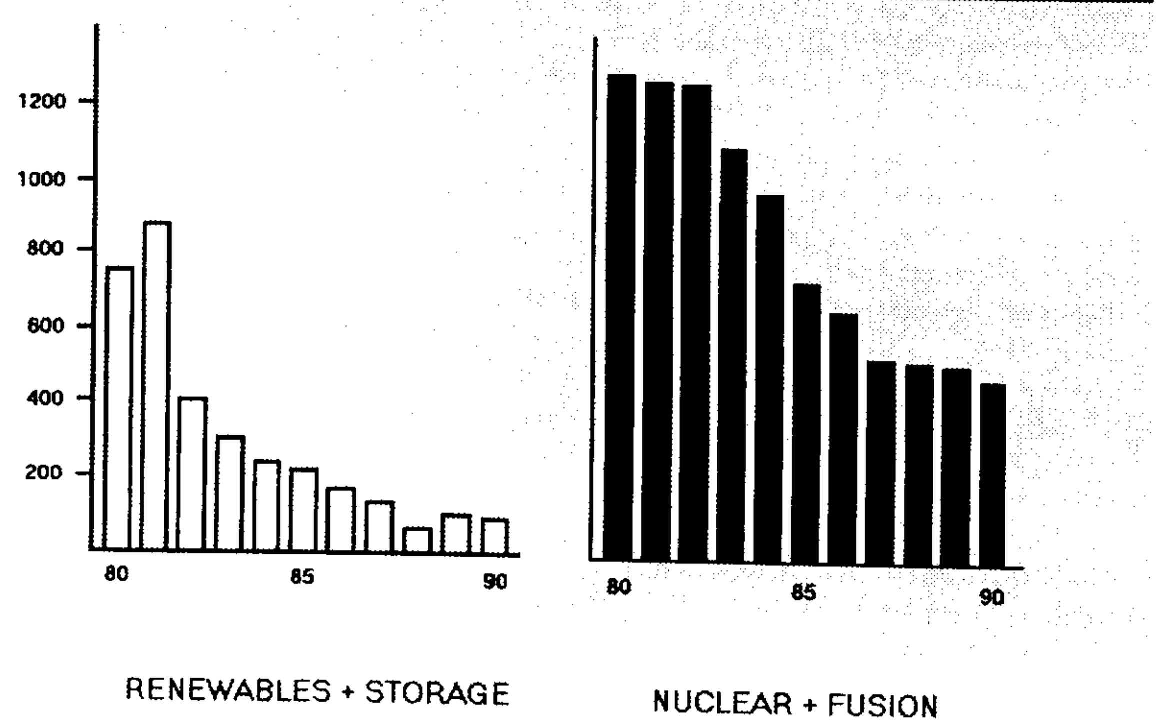
The social costs of electricity produced by nuclear and fossil fuel have been already quantified in some countries. They belong to three main categories: environmental, economic and government subsidies. Their relative importance decreases in the same order.

The main effects produced by the massive burning of fossil fuels and the ensuing environmental perturbations are indicated in *Figure 3*. The expected damages to life and to the economy, as well as the climatic changes produced by these large emissions, are the subject of other papers in these proceedings and will not be detailed here.

The reactor accident at Chernobyl in the former Soviet Union in 1986, led to a large release of radioactivity into the environment, equivalent to the fallout from a large nuclear explosion. Long distances were travelled by the radioactive cloud and, as a consequence of the accident, 28,000 delayed cancer fatalities are expected to occur in Europe. The most important lesson from Chernobyl, for the entire world, is that large scale radioactive releases to the atmosphere can have extensive transnational impacts for which no country is adequately prepared.

Besides the release of radioactivity into the

Figure 2. Research and development: an unequal battle. The figure shows the US Department of Energy R&D budget for 1980-1990 (in millions of 1982 dollars)



* INTERNAL AND EXTERNAL COSTS OF ELECTRICITY GENERATION

* FOSSIL AND NUCLEAR FUELS:

\# CO_2, SO_2, NO_x :
Greenhouse effect
Danger to the ozone layer
Urban air pollution
Global oil spills
Acid rain, deforestation

\# Nuclear wastes and release of radioactivity into the environment

Figure 3. Including the environment

environment by nuclear generating units, the as yet unsolved problem of nuclear waste is a matter of high concern. In the USA, the estimated total cost for cleaning up and improving the safety of the nuclear weapon complex is of 150 billion US dollars.

Energy Consumption and Quality of Life

Another relevant question concerning the future of photovoltaics addresses the possible impact of photovoltaics in the developed and in the developing countries, in other words, how much photovoltaic energy would contribute to the satisfaction of the energy needs of the rich and of the poor. To that aim, consider *Figure 4* where, for a large number of developing countries, a parameter called ***physical quality of life index*** has been plotted against energy consumption. The physical quality of life index focuses on three measures of wellbeing: infant mortality rate, life expectancy and literacy. These indicators are assumed to reflect the most basic desire of people: to live longer with better health and opportunity. The physical quality of life index consolidates these three, ranked from 1 to 100, into a composite index on the basis of the countries of the world having the worst and the best performance. All other countries are ranked accordingly. Advanced countries fall in the mid to high 90s. The developing countries, indicated by dots in the figure, fall anywhere from 15 to 90.

A clear correlation appears between the quality of life and energy consumption, the most striking finding being the sharp rise in the physical quality of life index as energy consumption increases from its lowest values. The benefits are more than proportional in the low consumption side of the curve, an indication of the kind of impact any extra energy may have on the living conditions of the poorer of the world. The curve relating wellbeing to energy consumption possesses a threshold at approximately 20,000 kcal/day per capita, the physical quality of life index having reached into the 80s. This value should be interpreted as the value corresponding to the satisfaction of minimal conditions for human life.

It is interesting now to discuss this energy input in economic and social terms, and to compare it with the energy needs of the advanced countries. The data displayed in this paper indicate that different considerations should apply to each group of countries. In advanced countries, the driving idea is to obtain electrical energy from the sun at the ***lowest possible price***. To that aim, large generating units interconnected, or not, to already existing power grids are planned and built, the point being to feed the distribution network at the lowest price. This extra energy is needed not only for industrial purposes but also for home air conditioning and comfort, advertising, advanced transportation and communication systems, and other uses which are far from the subsistence level of the poor.

In the Third World, and particularly in the rural areas where the energy problem is more severe, the needs are different. As already mentioned, energy deficiency condemns millions of

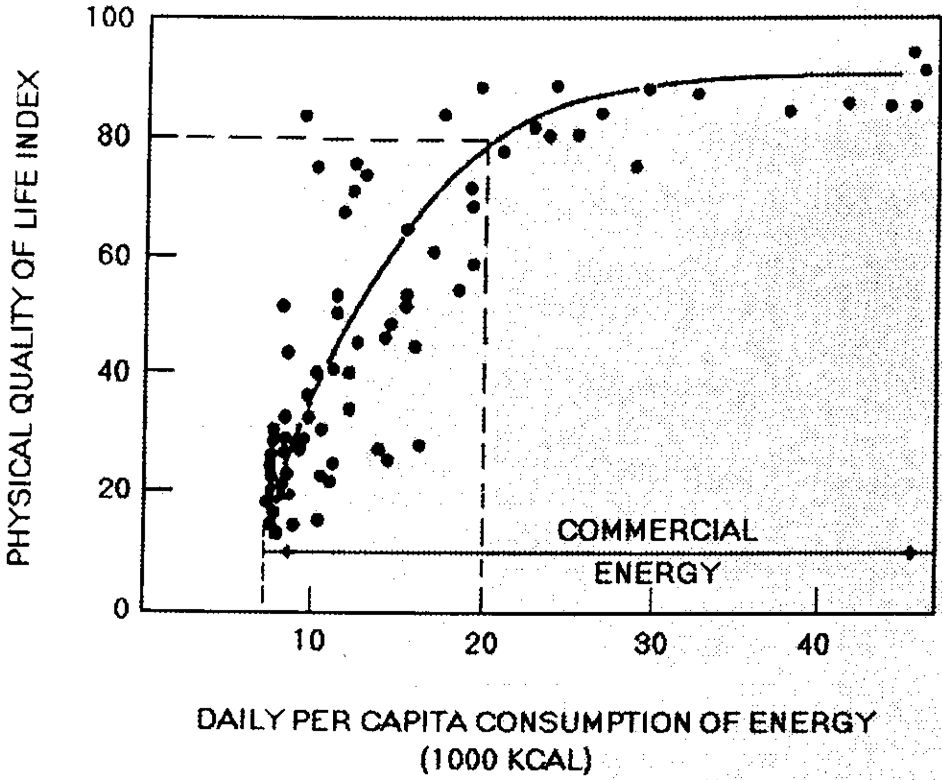


Figure 4. Relationship between physical quality of life index of Third World countries and energy consumption

human beings to live outside of the most basic benefits of civilisation. **The maximum affordable price of electricity at each end of the physical quality of life index curve is certainly different because the return of the solar kWh in terms of increased human wellbeing and productivity is different.** Electricity for non-essential uses or needed to feed a wasteful society has to be very cheap. Energy used to produce a substantial increase of the human quality of life or to foster development must be considered differently. In this sense, no universal figure for an optimum or competitive price of the solar kWh exists. In my opinion, these aspects have not been sufficiently considered by energy planners.

Conclusions

Renewable sources of energy, as impressive as their progress may have been in recent years, are not sufficiently considered by policy makers. Solar electricity generation faces a difficult situation because advanced countries do not establish energy policies that: a) promote a substantial effort in research and development of new technological options; b) guarantee the equity of the actualisation rate for different energy technologies; and c) include the social costs of conventional electricity generation into the tariff system.

The relative cost of energy transformation and handling is a fundamental parameter to be considered. In Third World countries, however, the likely impact of commercial energy in terms of increased quality of life and productivity should be properly included in the calculations. As already shown, any extra energy produces large benefits in regions of low consumption levels.