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CHOICE OF ENERGY TECHNOLOGIES:
The Case of Iran

Kavoos MOHANNAK

I. Introduction

The debate about energy has increased at local, national and international levels for two decades. But the nature of this debate has changed radically over that period. The 1970s emphasized an oil crisis that was more political than substantial. The major issue was who controlled oil, and at what price. In many countries, especially the developed ones, this led to focusing attention not only on the accessibility but also on the durability of energy resources. This also led to issues concerning the conservation of energy resources, particularly petroleum, both through more efficient burning of petroleum and coal and through the use of alternative fuels.

In most developing countries, however, the energy crisis of the 1970s took on a very different meaning. Oil importers suddenly accumulated massive debts as the price of oil rose. Consequently, the same oil crisis which led to a push for technological innovation in developed countries had precisely the opposite effect in many developing countries, where the push was more for daily survival.

Nevertheless, the exception was in areas of energy which are based on blending the results of new scientific and technological research with traditional energy technologies which have for centuries been based on the use of water, sun, wind and waste. As a result, some countries were able to investigate the potential for developing new technologies using, for example, biomass, solar thermal, wind and mini-hydro energy. In some countries as well, where the scientific and technological base was already sufficiently sophisticated, governments gave strong centralized support to energy-related innovation, as was the case with Brazil and its alternative fuels and energy efficiency programs.[1] But these countries were the exceptions.

In the case of Iran, a member of OPEC and with abundant and relatively low cost of fossil fuels, there was no serious need for any major program to develop alternative sources of energy. However, considering the fact that Iran's oil reservoirs are limited, and that in order to save these valuable resources for coming generations, it is necessary that alternative energy sources also be utilized. For this purpose, in this article after introducing some characteristics of energy technologies and their applicability in developing countries, it is attempted by focusing on renewable energy sources to suggest appropriate choices of energy technologies, especially, for underdeveloped regions of Iran.

II. Energy and Development

Economic growth, social mobility and cultural expression are impossible without energy. It fires our industries, fuels our agriculture, and keeps our houses warm or cool. It enables us to cook our food, pump our water, communicate and travel from place to place. The energy for these everyday activities is so abundant and accessible in the industrialized world that consumers have tended to take it for granted, thinking only in recent years to consider their overdependence on fossil fuels and the implications this has for the global environment.

Media attention to the phenomenon of global warming related to the buildup of "greenhouse" gases such as CO_2, NO_X and SO_2 in the earth's atmosphere, has promoted use of cleaner fuels and energy-efficient technologies. It has also helped to promote public awareness to the fact that pollution, wherever it occurs, can have consequences reaching far beyond the borders of those directly responsible for it.

The scientific, public, and political forces are now at work in the industrialized world to change consumption patterns of the consumers. Moreover, they address the need for new and renewable sources of energy. However, this will take a much longer time to influence the developing world who have limited financial, technological options for change at their disposal. It is obvious that they will need help to develop sustainable patterns of development and that the cost of ignoring their needs could be astronomical for the world.

Population growth and rising standards of living caused energy consumption in developing countries to grow from 14 percent of the world total in 1973 to 22 percent in 1987, and it could exceed 32 percent in the year 2020.[2] Over the next few decades, the population of these nations is likely to treble, and their energy demand could quadruple.[3] Therefore, the type and amount of energies which they consume will have a profound effect on climate and development at home and abroad.

Thus, energy is one resource which has to be managed wisely. It enters both on the shorter and on the longer time-scales of any development program. In this respect, some aspects of energy management and its characteristics will be the subject of the following sections.

III. Some Characteristics of Energy Technologies

1. Fossil Fuel Conversion

Fossil fuel consists of oil, natural gas and coal. Since the 1950s oil has been the dominant source of commercial energy in the world. Despite the renewed emphasis on the development of other sources of energy, oil will continue to supply about 30 percent of the world's commercial energy demand during the remainder of this decade, and a much higher share of the demand for commercial energy in oil-importing developing countries.[4)]

Natural gas refers to hydrocarbons, usually predominantly methane, which are found in a gaseous state in underground reservoirs. They may occur alone (nonassociated gas) or in conjunction with crude oil (associated gas). Production of associated gas dissolved in oil depends on oil production, and is therefore interrupted whenever the latter is shut down for economic or other reasons. Nonassociated gas production depends on the structure and characteristics of the reservoir, and is therefore developed on the basis of the size of the market and the overall viability of the project.

Coal, like oil and gas, is a fossil fuel derived from the sun over geological time. It has a critical role to play in the transition years, and it will be a continuing feedstock for hydrogen and synthetic hydrocarbons, but it cannot be considered a primary, long-term energy source. In 1950, coal was the world's most important source of energy, accounting for 59 percent of primary energy production, while oil provided only 30 percent.[5] By 1973 coal's share of world energy supplies had fallen to 29 percent, whereas oil's share had increased to 51 percent.[6]

The technologies involved in fossil fuel conversion, the application and some of the possible problems, concerning environmental impact and safety, are shortly summarized:

(i) Resource extraction (problems for coal in particular, but also for off-shore technologies and oil shale extraction),

(ii) Handling (hazards include those associated with transport of natural gas in liquid form, dust from coal, etc.), and

(iii) Use (in power plants, stationary and mobile engines, burners, pollution problems, modest safety problems, impact of carbon dioxide and waste heat in a long perspective).

In general, the convenience of fossil energy resources, such as their high energy density, makes them sustain wasteful uses, as long as they are cheap. Until the present, they have been very inexpensive to extract. However, the social impact of cheap fossil energy is substantial: "automobile societies," in which the car transportation dominates planning in regard to settlement pattern, location of industry and commerce, and profoundly influences lifestyles. In some sense societies have become accustomed to low-price fossil fuels, meaning that usage patterns have been adopted, which will be difficult to abandon once the fuel prices rise substantially.

The countries without fossil resources are in a very critical situation. They strongly depend on the fuel-exporting countries and multinational companies, implying uncertainty of prices, uncertainty of supply security, and placing a heavy burden of foreign currency expenditure on their shoulders which effectively reduces the possibility of intensifying the development efforts. An obvious recommendation to these countries would be to diminish their fossil fuel dependency as quickly as possible by building up alternative energy systems not characterized by such problems. It should not be forgotten, however, that presently most such alternatives are more expensive, although they may require little import of materials or skills. Also, demand for fossil fuels in the long term, especially for oil and gas, will deplete global reserves to the point where prices will rise dramatically. On the basis of current estimates, global resources are probably sufficient for 50 to 100 years at present and projected consumption levels.[7)]

Thus, the implication for both importing and exporting countries may be a reduced rate of development, even if the supply security problem is solved. Therefore, a wise policy would be a proper balancing between building up a national energy system independent of imported fuels and technology, and yet taking advantage of cheap fossil fuels, in some quantity, for as long as they remain cheap.

2. Nuclear Energy Conversion

Nuclear energy technologies are very complex technologies, some of which are not fully developed, and most developing countries would have to import these technologies in their entity (equipment and fuel), in order to make use of them as energy sources. Thus, they would weigh heavily on the foreign currency balances, and they would be controlled by foreign experts or by an elite of highly educated local people. Since nuclear technologies are tied together with the potential for nuclear weapons production, the usage in which know-how is transferred to an elite within the importing country is one that may allow the establishment in control (e.g. government or military) to begin a nuclear arms technology, which would otherwise not be an option open to it.

Further, social impact of nuclear energy may derive from each step in the fuel cycle, fuel extraction and handling, usage (in fission, eventually fusion reactors, with inherent safety problems, and waste heat impact), and treatment or radioactive residues as well as waste storage. Moreover, nuclear plants raise a variety of safety and environmental issues including the possibility of loss of coolant,[8] the hazards involved in transporting fuels, and the difficulties of processing, storing and disposing of radioactive wastes.

The safety problems may for a developing country be difficult to handle during an initial period due to lack of sufficiently trained personnel and lack of experience in quality inspection of equipment, etc. These problems are in any case amplified by the large reactor unit size chosen by the nuclear industry, which also make these energy sources inadequate for countries with modest electric grid sizes and little inter-regional power exchange capability.[9] However, countries that will have large enough power systems by the turn of the century should consider now whether they wish to include nuclear plants in their plans for the twenty-first century, usually as alternatives to other plants and in the context of current safety and political issues affecting nuclear energy.

3. Solar Thermal Conversion

The simplest solar thermal conversion techniques aim at heat production for hot water and space heating, the latter application being restricted to areas with a heating requirement; and in any case sufficient insolation is necessary.

Other applications include the production of process heat for industrial processes, an application of solar energy particularly useful for developing countries in high-insolation areas. In this way, they may build up a competitive industry independent of oil supplies. Further, there are space cooling and refrigeration applications, e.g. using a simple absorption cooling thermodynamical cycle driven by solar-absorbed heat. Solar-driven thermodynamical cycles may also be used for thermo-electrical power generation. In an economic evaluation, this system would have to be compared with photovoltaic power production.[10)]

The range of technological solutions to solar thermal conversion, from very simple systems to complex ones, may not be particularly difficult for use in developing countries. Because developing countries may start with equipment that is less than optimal and gradually improve it. No environmental or social drawbacks are expected from solar technologies of the kind discussed here. An exception may be the high demand on resources (materials used in equipment relative to energy output), which characterize some designs of solar thermal converters. It is expected that the efforts to reduce cost will also remove most of this problem.[11)]

Currently flat-plate solar collector systems for space heating and hot water have reached technical viability in several parts of the world. Hot water systems are in widespread use in areas with low space heating requirements, but they can only be considered economic when they can be integrated into the roof structure of new buildings.[12)]

4. Solar Photovoltaic Conversion

Among the direct solar conversion techniques producing electric power, photovoltaic conversion has been devoted probably the most effort. Photovoltaic technologies provide a reliable source of energy in remote areas of the developing countries where power requirements are small but important, as in the cases of communications and refrigeration, or power sources for health facilities. In areas where supply needs are small, sunlight is abundant and the water table is high, photovoltaics are competitive with diesel power for pumping.[13)]

Therefore, photovoltaic systems may find applications on many scales and may be ideal for decentralized use. The cost is presently high, in part due to the cost of the cells, and in part due to the size-to-power ratio of external support structures and transformer units. However, the solar cell price is going to go down, as a result of innovative technological efforts.

The solar photovoltaic technologies hardly involve any fundamental environmental or social problems. However, for developing countries an important question is, whether this is a technology that has to be imported or not. At present it appears that a problem may arise due to the high technological level required in solar cell manufacture. Those developing countries without such industry may become dependent on imports of cells. Also, with oil fuel costs at their present level, they are still too expensive for consideration as a replacement for bulk power generation.

5. Wind Energy Conversion

Wind energy is used mainly in developing countries for mechanical pumping, and when wind regimes are good and the volume of water needed is low, it compares favorably with diesel power. In general, two types of application of wind energy converters, which may be horizontal-axis or cross-wind rotating devices, may be distinguished. For some applications (e.g. lighting and industry), a dependable power supply is essential, and a kind of energy storage has to be incorporated. In this case electric power is the most convenient form of windmill output, and the energy storage may be a battery, or pumped hydro-storage, if hydroelectric resources are utilized in the same region.

Wind energy utilization is a well-established technology, but it should be kept in mind that the best wind conditions on the average are found in the temperate zones, and that several countries in the equatorial zone have a very low wind potential.[14] Therefore, where conditions are suitable, wind energy would seem to be the present, perhaps most viable, source (along with hydropower) of electricity from a nonfuel resource, at the same time because it offers the possibilities of centralized as well as decentralized uses.

Currently horizontal-axis wind turbines have been perfected and have gained a fair market position in some countries, and their use has recently spread to other areas as well. In regions with good wind conditions, they are cost competitive or almost competitive with fuel-based alternatives for bulk electricity production up to 25 percent of demand.[15] A factor in their competitiveness is that service and maintenance be available locally.

6. Other Technologies

It is also possible to mention further conversion techniques of interest. First let us consider technologies based on water.

Hydropower which has already been mentioned in the last section, has a very great potential in some areas. In such regions, it is reasonable to regard it as the primary source of high-quality energy. Most previous utilization has concentrated on plants of very large unit size, and in many cases has been associated with substantial risks derived from the possibility of dam failures. It should not be forgotten, however, that options for both small- and large-scale uses exist. Also, the small-scale hydro resources found in abundancy in most mountainous regions offer excellent possibilities for decentralized applications in less-developed regions. At present, the expansion of large-scale hydropower is approaching saturation because of cost and environmental reasons, but continued development is making small-scale hydro plants cost-effective in many places.[16]

Wave energy is another source of energy which is the result of systematic wind influence on a water surface. The use of wave energy is still in the early developmental stage and prototype installations have had their problems.

Geothermal energy conversion is another method already in widespread use, both for electricity production and for heat supply.[17]

Currently geothermal reservoirs have been successfully tapped for electrical power generation in many developing countries although there are several constraining factors including: resource location versus electrical loads, the ability to assess accurately the capacity of the reservoirs to be tapped, and the quality of local maintenance and management personnel. Also, most utilization has been restricted to areas of particularly favored geology.[18)]

Among other potential energy sources, bio-conversion should be considered. The main purpose of bio-conversion is food production. However, non-edible portions of plants may be considered for energy purposes. The burning of biomass remains widespread in developing countries and in forest-rich industrialized countries,[19)] despite adverse environmental effects. Also, biomass-based power generation has increased application in some countries. The possible role of biomass products as gasoline substitutes should be stressed for application in the transport sector; biomass-derived fuels really fill a gap in renewable energy technologies.[20)] The production of liquid biofuels continues in a number of countries, but on a direct economic basis this cannot currently compete with fossil fuels. At present biogas production operates at two levels.[21)] The first is in relatively primitive, labor-intensive domestic and other facilities. The second is in fully automated plants in industrialized countries. Therefore, if the use of biomass is modernized and much higher conversion efficiencies are achieved, it can provide an abundant source of renewable energy.

In sum, the attention that has been recently given to renewable sources of energy focuses on the development of technologies for the better harnessing and more efficient use of these and other renewable sources of energy. At present renewable energies command 25 percent of the total energy use, including non-energy uses such as those in the timber, paper and pulp industries.[22) Among these resources, biomass and photovoltaics are the most promising future renewable energy sources. Their potential contribution to world energy supply is substantial, as is their potential to stimulate sustainable development and to displace current energy systems which are causing serious environmental degradation.

IV. Energy Technology and Society

The choice of energy technology influences a given society in several ways, such as by demanding certain skills and education, by introducing certain usage patterns, by placing emphasis on conservation or oppositely on wasteful habits, and by determining the scale of certain infrastructures. The choice of energy systems may also influence environmental attitudes of the population in general, and in some cases, it may relate to military policy. Another type of influence also may be found. For example, settlement patterns and the organization of production and consumption favor some energy systems and disfavor others.

Dominant factors in the overall selection of energy technology may be its capability of preserving the prevailing distribution of economical or political power, or to create a distribution of power desired by groups in society, which are able to influence decisions on energy policy. These groups may be those possessing political power to choose among different energy systems, or they may be industrial manufacturers inside or outside the country, which have the power to determine the range of energy systems or other technologies that are to be offered commercially on the market. Clearly, it is very difficult, politically, to choose an energy system which is feasible but which has not appealed to industry to such an extent that it has been commercialized.

Of course, the political and social structure is not uniquely determined by choices of energy or other technology, nor is the opposite influence unique. Still, these choices may push the development in a definite direction, and they may show more or less compatibility with different social structures and political-economical types of organization.

For the developing countries, particularly, the choice of energy and other technologies can have strong influence on the kind of society emerging. Some choices will promote the development of large concentrations of economic activity, enhance the influx of people to the large cities, and preserve the power and profit in the hands of a minority.

Other choices are more likely to promote the development of rural areas, and by spreading the economical activity also make it easier to follow a policy approaching a more equitable distribution of profits. As it is understandable from the discussion of individual energy technologies in the previous section, it is likely that at least some of the renewable energy technologies are compatible with or directly stimulating for an equitable distribution policy, while the nuclear technologies are certainly not. The fossil fuel technologies are sort of "in between," in the sense that they may serve appropriate development goals in a specific period, but their suitability is counteracted by the multinational control structure, when viewed from the point of view of nations without domestic resources of fossil energy.

However, the situation is not too different from that of capitalist nations or fuel-exporting countries, because they also aim primarily at increased production, and they also pollute and abuse resources, which could have been used elsewhere to satisfy more basic development goals. This does not imply that precisely the same technologies should be used everywhere. Of course, one set of technologies would be appropriate in one region and another one in another region, but the important thing is that the general social implications of basing the energy supply on sources will become common for all regions of the world. It means that energy policy should emphasize optimum use of available resources with full consideration of its socio-economical-political consequences.

V. Energy Choice for Iran

Taking up the main aim of this article, it is necessary to outline briefly suitable energy technologies for Iran. As already mentioned, the abundance and relatively low cost of fossil fuels in Iran, particularly natural gas, preclude the need for any major program to develop alternative sources of energy. Given the current stage of development, complex technology and high cost of sophisticated energy technologies, it is important that alternative energy sources also make a substantial contribution in Iran's energy policy. Particularly, energy policy should emphasize different energy technologies with respect to "appropriateness" for underdeveloped regions of the country.

In this regard, the technologies based on renewable energy resources, due to their compatibility with a decentralized development of rural areas, can be an appropriate choice. Therefore, an important social advantage of the development of renewable sources of energy is the potential for development in rural areas of Iran. Petroleum-based fuels and electricity are less widely available in rural areas and generally more expensive than in urban areas. Yet through the use of appropriate technology and by proper management, a wide variety of renewable sources of energy can be harnessed to meet the essential needs of the poor, offering them a better quality of life. However, it would be incorrect to imply that the energy choices of the advanced technologies are less important for a country like Iran with abundant natural fossil fuels. But since the satisfaction of basic human needs should be a priority goal for any society, energy policy should also emphasize it. Thus, first we will examine prospects for fossil fuels of Iran and then we will turn to the question of alternative sources of energy.

1. Prospects for Fossil Fuels

a) Oil

Iran is endowed with major crude oil reserves, estimated to be 92.85 bn barrels at the beginning of 1991, equivalent to 9.3 percent of total world reserves.[23] Assuming production at 1990 levels, Iran has a projected reserve life of 82 years. In the five years before the Islamic revolution, Iran was producing an average of 5.5 million b/d, and it had climbed to as much as 6.0 million b/d in September 1978. After the

Islamic revolution the output level was dramatically reduced, due to external events as well as domestic policies. The Islamic government was committed to an output of less than 3 mn b/d, below which level it remained until 1990 (Table 1). However, Iran's target was to raise production capacity from a nominal 3.5 mn b/d to 4 mn b/d during 1991. Moreover, the Iranian oil minister said he expects Iran within 5 years to have the ability to sustain production of 5 mn b/d.[24]

Table 1
Crude Oil Production ('000 b/d)

1965	1975	1985	1986	1987	1988	1989	1990
1,908	5,350	2,192	2,037	2,298	2,305	2,814	3,148

Source : OPEC, *Annual Statistical Bulletin: Petroleum Economist.*

It should be noted that, actual production levels will depend on a number of political, economical, technical and market factors. While Middle Eastern observers may dispute Iran's ability to produce 3.5 mn b/d, there is no doubt that reserves can sustain 4 mn b/d during the next 10 years.[25] Of course, production capacity was restricted by damage to the oil infrastructure resulting from the war with Iraq, but since then there has been a constant effort for reconstruction of the oil industry.

The most crucial decision is whether Iran will continue to base its economy on the long-term value of its oil or focus on gas. In view of the significant export value of oil, on the one hand, and the physical constraints on oil production relative to such alternative sources of energy such as natural gas, on the other, Iran has long sought to limit the use of oil at home. But the rate of domestic oil consumption may rise rapidly with economic recovery or with a focused government effort to make more oil products available to users in urban and rural areas. Domestic consumption of oil may also be pushed up if programs for development of alternative energy sources are not met and, thus, the government is forced to fall back on oil products to satisfy rising demand for energy.

In fact, the level of natural gas use in domestic markets is the single most important factor in determining future oil product requirements in Iran. The interrelatedness of these two fuels, particularly with regard to their roles in meeting Iran's domestic energy requirements, cannot be overemphasized.

b) Natural Gas

Iran's proven reserves of natural gas, 600,350 bcf, rank second in the world only to those of the Soviet Union, and exceed the proven reserves of all the other Middle East countries combined.[26] A high proportion of current gas output, 854.4 bcf, is associated with crude oil production. On the basis of current reserve estimates and generous projections of domestic consumption, exports, and reinjection, Iran's natural gas reserves are expected to last well into the next century. Thus, the problems of natural gas supply in Iran do not concern physical availability but rather location of natural gas reservoirs and their efficient utilization.

Iran also has extensive reservoirs of non-associated natural gas fields such as that at *Qeshm*, whose potential is at least equal to that of the associated reserves. To date, nearly all of Iran's natural gas production has been in association with oil products from the *Khuzestan* and offshore oil fields. Minor quantities of non-associated natural gas are produced from the different fields.[27]

Therefore, considering the vast Iranian supplies of natural gas, the low production costs, and the relatively limited export prospects as compared with those for oil, Iran should pursue a vigorous policy of rapid natural gas development. Every effort should be made to accelerate expansion of natural gas transmission and distribution systems. However, building gas as a major source of exports and fuel for the domestic economy will involve major foreign assistance. In this regard President Rafsanjani said Iran should intensify exploitation of its gas reserves as "the best and richest source of energy," and that this should be a key part of the country's postwar reconstruction.[28]

As natural gas utilization increases, larger quantities of NGL will also become available because natural gas must be processed before it can be compressed for reinjection or transported through pipelines. This NGL can then be fractionated to yield ethane, natural gasoline and LPG consisting of propane and buthane.[29] Thus, the future availability of LPG in Iran will depend on the size and scope of the natural gas gathering program. In this way, the rate of increase in the domestic demand for oil products would be slowed down, saving oil for export or for future use.

c) Coal

Iran's coal resources are estimated at about 6 billion tons of which approximately 3.7 billion tons consist of high-grade coal suitable for coking or metallurgical use and 2.3 billion tons of lower grade product for use as steam coal.[30] Of the total resources, only one-tenth is judged commercially accessible at this time and included in proven reserve estimates; most of Iran's coal is located in deep, thin seams that are difficult and expensive to mine.

Iran's coal production is concentrated in the *Kerman* region and the output is used primarily as coking coal at the *Isfahan* steel mill.[31] The cost of producing steam coal is substantially higher in Iran than that of natural gas. Furthermore, the environmental problems associated with coal production and use make it less desirable fuel than natural gas or even residual fuel oil.

However, a modest exploration program should be continued to locate and identify coal reserves. For using coal in the future it is important to consider the economics of coal production, transportation and consumption change in relation to other fuels. It is recommended also that extensive research and development on clean coal technology be done in order to help Iran use more coal without harming the environment.

2. Prospects for Renewable Energy Technologies

New and renewable sources of energy in Iran, such as, solar, wind, hydropower, and geothermal and biomass, should play an increasing role to supplement needed fossil fuels and to increase the availability of rural energy for the country. Taken together, the full range of renewable energy sources represents a very large potential, if only a small fraction of this potential were to be realized, the contribution would materially affect the energy supply of Iran.

Activities in the field of new and renewable sources of energy may comprise general activities such as: resource assessment, need identification, research and development, development and demonstration, demonstration and extension/promotion and popularization. The activities in these areas would provide information and data for project formulation and feasibility studies for the extensive utilization of new and renewable resources of energy. However, the problems of spreading awareness of renewable energy systems are socio-cultural factors. In Iran like other developing countries where there have been certain traditional ways in which renewable energies have been used, awareness has to be promoted regarding newer techniques which offer more efficient ways of utilizing the renewable sources.

In what follows, some of the potential applications of renewable energy technologies in Iran will be reviewed, however we do not present a complete program or even the only correct path to follow; but we feel that they are sensible approaches to the major issues that must be on any reasonable energy policy agenda.

a) Solar Energy

Solar energy is everybody's great hope for the future. In fact, solar energy has many advantageous features: sunlight is inexhaustible, abundant, clean, distributed, and directly convertible to heat, fuel, mechanical energy and electricity. Yet, sunlight has two properties that impede its use as a direct energy source for the home, commerce, and industry: it is variable in time and has a low flux density. These properties require energy storage, energy concentration and large-area collectors.

Nevertheless, currently solar energy is the most promising and widely used renewable energy source and its application may considerably improve the fuel energy spectrum of the Iran. Since Iran has high insolation, great potential exists in utilizing solar energy. Perhaps one of its potentials may lie in the small-scale application of existing solar energy technologies in remote towns, villages and nomadic areas, including water heaters for communal bathhouses, milk heaters for milk processing and pasteurization, coolers for storing food and medical supplies, home space and water heaters, crop drying, and small-scale water pumping and desalination equipment. These applications in Iran are considered to be promising in conserving a considerable share of fuel consumed for these purposes.

The siting potential for solar energy in Iran is, nonetheless, considered very favorable. Some 60 percent of the country is classified as arid or semi-arid and Iran has one of the highest factors for insolation in the world.[32] A large portion of the population is distributed in small and remote villages and the high cost of distributing fossil fuels and transmitting electricity to these scattered villages enhances the relative attraction of solar energy. Consequently, solar heating and solar electric conversion using thermal or photovoltaic systems should have large-scale applications in Iran. Because great potential exists in utilizing solar energy through direct conversion of solar energy into electricity by photovoltaic methods, it is desirable that an experimental 5 MW prototype solar power plant be built in a suitable region of the country.

According to some quantitative studies, the greatest potential for solar heating application lies along the *Zagros* mountains from the province of *Fars* in the south and northward through *Hamadan, Kurdestan,* and eastern *Azarbayjan.*[33] The coastal regions along the

Persian Gulf and the Caspian Sea are the least favored areas for solar heating. The Caspian region has the lowest insolation in the country combined with a moderate heating requirement. At the opposite extreme, the Persian Gulf has excellent insolation, but very low heating requirements.

Accordingly, the potential for solar electric power applications is highest in the central, south-central and southeastern regions of the Iran, while the poorest prospects are in the Caspian region.[34] Therefore, Iran is in a position to make use more of solar energy both because she has more direct sunlight and because it offers a reliable source of energy for the future. Thus, government and private sectors should generate, assemble, and make widely known data and information on solar energy technologies and the likely impact of their deployment under various conditions to assist those people searching for types of solar energy of interest to them for specific settings.

It should be noted that we have not undertaken a detailed survey of solar energy technology.[35] Instead, we have used the basic characteristics of the broad types of solar energy technology to help us select a set of guiding principles that we recommend be incorporated in solar energy policy during the next few decades.

b) Wind and Geothermal Energy

Wind power and geothermal energy are other sources of renewable energies applicable in Iran. As already explained, a firm technical basis exists for geothermal and wind power projects, and they appear to be economically attractive for suitable sites.

The most important factor in determining the potential for wind energy are its characteristics such as, speed and pattern at the site. The windmills offer maximum efficiency in the areas where the average annual wind speed is equal to or exceeds 5 m/s. According to some surveys, the highest average wind velocities in Iran are in *Kerman, Sistan* and *Baluchistan* and eastern *Azarbayjan* which can be used for a variety of purposes on a village scale.[36] These include: pumping fresh water for domestic livestock and agricultural needs; irrigating fields; powering agricultural tasks such as grinding corn, wheat, etc.; generating electricity for a variety of purposes; cutting wood; etc.

Thus, small-scale wind machines are an appropriate choice for different applications in suitable sites in Iran. At present a variety of windmills is available, either commercially or in the form of working prototypes that could be readily manufactured. They include both vertical- and horizontal-axis rotational machines. Therefore, what is needed at the moment is more exploration of sites and availability of data in order to assess the potential role of wind energy in Iran. As a result, it is possible then to apply and adapt known technologies of windmill systems in a variety of environmental conditions of Iran. Moreover, it is also very important to develop a program of public education in rural areas to show what wind power can do.

It is also possible to utilize large-scale wind energy for the following purposes:

(i) Creation of independent driving windmills (1-15 kw) and wind DC power units for mechanizing hard labor in agriculture, water lifting irrigation, lighting and space heating;

(ii) Creation of AC windmills for parallel operation with thermal power plants;

(iii) Development of windmills for operation in power systems to use wind energy for industrial purposes.

In the case of geothermal energy, we should notice that there are at least five broad types of geothermal resources: hot water fields, dry steam fields, hot steam fields, hot brine fields and hot dry rocks. Of these, the first three have been exploited for electric power generation or as a source of direct heat, although hot brine has serious drawbacks for power generation such as corrosion, pollution and disposal of waste water. A study of the general geothermal potential in northwestern Iran undertaken in the 1970s identified four geothermally promising zones. These areas include *Sahand, Damavand, Maku-Khoy*, and *Sahand*.[37] However, additional surveys and exploration drilling are needed to define the nature and extent of Iran's geothermal resources.

c) Hydropower

Iran was one of the first countries that used flowing water for her energy needs in ancient times. This was possible with the help of special type of waterwheels. These waterwheels are the precursors of the present water turbine. Yet waterwheels have many applications, such as: grinding grain for flour and animal feed, raising water for irrigation and water supply, textile manufacture, and metallurgical processing. With the development of large-scale hydro and thermal-electric central generating stations, the manufacture of small water turbines began to decline rapidly. However, in recent years, because of the energy crisis, there is renewed interest in the small-scale hydroelectric unit. Such units are currently available for use in developing nations.

Iran possesses a fairly large hydropower potential at sites located exclusively in its mountainous western and northwestern regions. Also, there are vast possibilities for power development of a small-scale type, in combination with water supply development for irrigation, in different parts of the country. Therefore, both small- and large-scale power units can be used for energy production in Iran and for different purposes. For example, small-scale hydroelectric units can perform also useful mechanical tasks directly; it may be connected via belts or gears to grain mills, pumps, wood, and metal-working machinery, and other machines of production.

In addition to a number of promising hydropower sites which have already been identified and subjected to some engineering analysis, it is suggested that large-scale studies of the application of the simple hydroelectric power units should be undertaken in order to identify their applicability for remote and rural regions of the country.

3. Policy Implications

The review of the previous list of energy sources demonstrates the large potential of renewable energy sources for Iran. While some technologies have reached commercial maturity, those whose contribution is expected to be largest are very long term. Thus, the long-term nature of this endeavor should be re-emphasized, and sustained government support for its development will be required to realize its potential.

On the other hand, policy analysts and planners now realize that energy sector programs and policies have to be formulated on an integrated basis, in contrast to the prevailing practice of uncoordinated planning in different energy sub-sectors.[38] It means that the analysis of all the related issues need to be done in a unified policy framework to arrive at a set of nationally optimal energy solutions. Here we should emphasize the importance of co-ordinated energy planning with particular reference to the interrelationships among the policies adopted in various energy sub-sectors such as electric power, petroleum, natural gas, coal, renewable and traditional fuels. Integrated energy planning permits the development of a coherent set of policies which meet the needs of many interrelated and often conflicting objectives.

However, in spite of significant developments in concepts and methodology for planning and policy analysis of the energy sector,[39] in practice many countries may encounter serious obstacles in the implementation stage. These problems may be related to the lack of an energy data base in order to support effective energy planning and analysis or they may be related to institutional structures and manpower needs. In order to reduce the effect of these obstacles and based on the previous discussion we now offer some general policy guidelines on what we think should be done about energy problems of Iran:

—— to achieve environmental and energy objectives, ensure that effective co-operation occurs between ministries and with all parties concerned;

—— in view of the key role of energy efficiency in future energy policies, renew efforts to increase efficiency in both energy supply and demand to meet energy and environmental policy goals;

—— strengthen capabilities to analyze, and capacities for collecting and disseminating information on energy technologies and energy demand;

—— provide awareness and motivation of energy consumers in the industrial, residential and transport sectors on the advantage of saving energy, through intensive information dissemination;

—— enhance the further introduction of domestic natural gas consumption and facilitate and promote the use of liquefied petroleum gas in areas not served by natural gas;

—— priority should be given to improvement of availability and use of energy in rural areas, therefore it is suggested that the concentration of activities in the field of new and renewable sources of energy should be directed to improving rural energy supply;

—— projects in new and renewable sources of energy should be designed to promote the use of standardized methodologies for energy assessment;

—— emphasis should be given to demonstration in rural areas and pilot projects and high priority should be given to manpower training; and

—— in promoting renewable energy sources national program should define the following areas: (i) design and commissioning of solar power plants, (ii) design and construction of solar hot water supply, heating and air conditioning systems, (iii) construction and commissioning of geothermal power plants, (iv) development and construction of geothermal heat supply systems, (v) development and implementation of windmill units and wind power plants, (vi) development of the country's hydropower resources, and (vii) introduction of the new bio-conversion technologies.

This list may provide both the private and public sectors with an extensive R&D menu and promote the balanced development of energy planning skills both at the management and technical levels.

VI. Concluding Remarks

Iran is endowed with relatively large renewable energy resources, in addition to abundant fossil resources, such as solar, wind, geothermal, hydropower, etc. These resources are particularly well suited to meeting the widespread need for small, decentralized sources of energy in rural regions where, owing to the lack or high cost of energy from conventional sources, renewable energy may prove economical. The pace at which Iran can exploit her renewable energy potential will be determined by her ability to create or strengthen institutions for this purpose. Progress can easily be hampered by the lack of a coherent national energy plan within which the role of renewable energy can be defined, priorities among the various technologies determined, and resources assigned, especially when programs to develop renewable energy sources begin to require important policy and budgetary commitments. To use these resources on a wide scale will require extension and other delivery systems that are capable of reaching the urban and rural poor with technical and social assistance and credit facilities.

The other area of fundamental importance in renewable energy development is research and adaptation of techniques to local conditions. In this regard, Iran may find herself short of the expertise needed to evaluate and exploit these resources. Also, there may be important gaps in the ability to select from and adapt to her needs the technologies being studied and developed by the industrialized countries, and especially technologies whose greatest potential is in the rural areas. To fill these gaps, attention needs to be given to strengthening national research on specific renewable energy technologies.

NOTES

1) For a comprehensive survey of Brazil's energy programs, see, Smil, V. & W.E. Knowland (eds.), *Energy in the Developing World: The Real Energy Crisis* (New York: Oxford University Press, 1980), pp. 223-264.
2) *ATAS* News, No. 13, Summer 1991, p. 1.
3) *Ibid.*
4) World Bank, "Energy in Developing Countries," in P.K. Ghosh (ed.), *Energy Policy and Third World Development* (Westport: Greenwood Press, 1984), p. 19.
5) *Ibid.*, p. 35.
6) *Ibid.*
7) UPDATE, *Renewable Energy: Issues for the 1990s*, No. 46, (New York: UNCSTD, Summer 1991), p. 1.
8) It should be noted that this problem was one of the major problems that happened several times in the nuclear reactors of the industrialized countries.
9) Sorenson, Bent, "Some Characteristics of Energy Technologies," in H. Buchholz & W. Gmelin (eds.), *Science and Technology and the Future*, Vol. 2, (Munchen: K.G. Saur Verlag, 1979), p. 1332.
10) In photovoltaic power generation, semiconductor cells are used to generate electricity directly from the sunlight, by separating charges in specially treated semiconductors.
11) We should note that site-specific factors related to climate and market have a major bearing on the viability of solar power. Solar systems are often competitive with other options for water heating and drying but much depends on the local availability of low cost materials and equipment.
12) Sorenson, Bent, "Renewables Provide 25 p.c. of Global Energy," in UPDATE, *op. cit.*, p. 4.

13) Navigilio, A., "Market Remains Small for Small Energy Resources," in UPDATE, *op. cit.*, p. 5.

14) Sorenson, B., "Some Characteristics of Energy Technologies," p. 1336.

15) Sorenson, B., "Renewables Provide 25 p.c. of Global Energy," p. 4.

16) In the field of small-scale hydropower, photovoltaic is a proven and common technology for the production of off-grid electricity and the generation of shaft power, although low capital costs, good water conditions, and high-load factors are necessary if small hydropower is to compete with other resources.

17) Geothermal energy is derived from the natural heat of the earth. It is extracted as heated fluid, usually water or a mixture of steam and water, but sometimes dry steam.

18) For example, in Iceland, Italy, New Zealand and the United States, geothermal energy has been employed for space heating, hot water supply, process heat and electric power generation. Among developing nations, El Salvador, Indonesia, Kenya, Mexico, Nicaragua, the Philippines and Turkey are using geothermal energy.

19) Biomass energy includes a variety of energy sources, such as wood (or charcoal) as well as methane or alcohols (methanol or ethanol) produced from various agricultural, industrial or domestic wastes.

20) For evidence see, World Bank, *op. cit.*, pp. 44-45.

21) Biogas, a mixture containing 55-65 percent methane, can be produced from the decomposition of animal, plant and human wastes.

22) Sorenson, B.,"Renewables Provide 25 p.c. of Global Energy," p. 4.

23) The Economist Intelligence Unit (EIU), *Iran: Country Profile 1991 - 92* (London: 1991), p. 28.

24) *International Petroleum Encyclopedia* (*IPE*), Vol. 24, (Tulsa: Energy Group of Pennwell Pub., 1991), p. 96.

25) *IPE*, Vol. 23, (1990), p. 125.

26) EIU, *op. cit.*, p. 28.

27) Mossavar-Rahmani, B., *Energy Policy in Iran: Domestic Choices and International Implications* (New York: Pergamon Press, 1981), p. 71.

28) *IPE*, Vol. 24, p. 124.

29) Mossavar-Rahmani, *op. cit.*, p. 83.

30) *Ibid.*, p. 89.

31) *Ibid.*

32) *Ibid.*, p. 91.

33) For a detailed study of the quantitative survey, see, *ibid.*, pp. 91-95.

34) *Ibid.*, p. 95.

35) For more information about solar energy technology, see for instance, Goodenough, J.B., "Prospects and Scope for Solar Energy," in A.B. Zahlan (ed.), *Technology Transfer and Change in the Arab World* (Oxford: Pergamon Press, 1978), pp. 401-431.

36) Mossavar-Rahmani, *op. cit.*, p. 95.

37) *Ibid.*

38) On this subject see, Munasinghe, M., "Integrated national energy planning in developing countries," in P.K. Ghosh (ed.), *Energy Policy and Third World Development*, pp. 199-212.

39) For example, various planning tools have been developed, including: the reference energy system approach, input-output (or inter-industry) analysis, energy economy linkage modelling, and the generalized equilibrium approach.

Key Words: Energy Technology, Iran, Renewable Resources, Choice of Energy, Energy Policy