Residential Solar Energy Use: 
barriers and incentives in a historical perspective

by

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Abstract:

Energy crises have triggered increases in solar energy use at various times in the past 2500 years. A surge of interest in solar energy was experienced in the United States in the late 1970's. This interest has since declined. Still, concerns about dependency on imported fuels, the environmental effects of current energy sources, and depletion of nonrenewable resources mean that renewed interest in solar energy may not be far off.

Residential solar use is particularly attractive for reducing energy dependencies, so assessing strategies to encourage the greatest number of residential users is important. Past experience has shown that different conditions, or strategies, produce varying results ranging from widespread community solar use to limited upper class elite use.

Diffusion theories provide a basis for understanding patterns of solar technology adoption. Studies of previous attempts to stimulate residential solar energy use are used to identify the barriers and incentives which affect the diffusion process. Physical, economic, and social barriers
to adoption are identified, and alternative incentives used to reduce these barriers are evaluated in terms of their effectiveness.

**Introduction**

Energy crises in 1973/74 and 1979 stimulated United States' investment in solar energy. During this time period, money poured into renewable energy research and development, educational programs were formed to promote solar use, and federal and state tax incentives were provided for residential solar users. The solar industry grew steadily throughout the 1970's.

However, in 1981 research and development funds for renewable energy were reduced and by 1984 funds were only 25% of what they were in 1980 (Seideman, 1984). Still, the solar industry maintained its integrity until 1986 (see figure 1) when federal tax credits expired and as oil prices steadily declined throughout the 1980's (see figure 2). The solar industry sales fell 80% in 1986 (National Wildlife, 1987).

Interest in solar energy is again growing. Federal funding of solar research and development programs is increasing rapidly. Funding for photovoltaics went up 33.8% in 1991 and Congress has proposed to increase it another 30.5% in 1992. Funding for solar thermal technologies
Solar Collector Production (according to the Solar Industries Association, adapted from National Wildlife 1987)

FIGURE 1
40. 30. 20. 10.

U.S. Imported Crude Oil (dollars per barrel)

Premium Leaded Gasoline (dollars per gallon x 10)

FIGURE 2 (U.S. Dept. of Energy)
increased 20.8% in 1991 and has Congressional support for an additional 51.6% in 1992 (Sklar, 1991). Increasing energy production with minimal environmental damage drives the renewed interest. There is concern that pollution from fossil fuel burning is contributing to an increase in global temperatures. Also, recent unrest in the Persian Gulf, a major world oil supply area, increased uncertainty about current oil supplies.

Increased residential solar energy use might reduce the need to buy and burn fossil fuels. Solar designs are effective. Solar heaters can save 50-75% of the fuel necessary to meet residential hot water needs (D'Alessandro, 1987). Passive solar designs for houses can supply 40-80% of the heating energy even in less favorable climates (Wayne, Hall, and Behler, 1986). Thus, as renewable fossil fuels diminish or concern over their use increases, solar energy is stressed as an alternative.

The purpose of this research paper is to examine previous experience with residential solar use and to evaluate its effectiveness. To do this, historical examples are presented and discussed. Next, diffusion theory is reviewed as a way of providing a framework for looking at solar energy adoption. Then from a literature review, physical, economic, and social barriers to residential solar use are identified, and incentives which have been used to reduce these barriers are evaluated.
Solar energy has been used in residential areas for thousands of years. Twenty-five hundred years ago, in ancient Greece, fuel wood became very scarce. Laws were passed restricting the use of wood and charcoal. This prompted the development of alternative energy sources, such as, the abundant free energy from the sun. The Grecians began designing buildings to be more solar efficient. They used direct sunlight to heat homes in the winter and overhangs on their buildings to provide shade and cooling in the summer. Not only did individual buildings utilize solar designs but whole cities were planned and built with respect to the sun (Butti and Perlin, 1980).

A similar wood shortage prompted use of passive solar design in the Roman Empire beginning around the first century B.C. The Roman empire covered a larger more diverse area. Different designs and strategies were implemented in the different regions. In addition to orienting buildings southward, they added mica or glass to windows in order to help trap the heat inside. Solar water heating became important for public bath houses. By the first century A.D., solar access laws were passed that did not allow objects to be placed in such a way that blocked the sun from reaching bath houses. Despite these wood shortages and advances in solar design, solar use was limited mainly to
the wealthy elite in the Roman Empire. Those who could afford it selected appropriate sites and built with a solar design. The poorer people only enjoyed the benefit of solar in the public bath houses (Butti and Perlin, 1980).

Solar energy use was not limited to ancient Greece and Rome. It has been used in one form or another since time began. Interest in solar energy uses has had its ups and downs for various reasons throughout time. One example of this up and down cycle is seen in Southern California.

In Southern California in the early 1900's, water was heated using firewood. Only a small amount of water could be heated and used at one time. So, inventors began experimenting with solar water heating to make life easier for people. By the end of WWI over 4,000 solar water heaters were sold in Southern California. Then in the 1920's abundant natural gas supplies were discovered in Southern California. Gas companies provided economic incentives to make it extremely cheap and easy for homeowners to use gas to heat their water. This drastically reduced the solar market in Southern California (Butti and Perlin). Later, the sky-rocketing oil prices in the late 1970's caused another look at the benefits of solar energy use in California, as well as the rest of the United States.

Although these three examples do not represent the complete spectrum of past occurrences, nor do they dictate what the future will hold, they do give some indication that
in this human-resource relationship, physical, economic, and social related factors may influence the adoption of residential solar energy. Triggering the rise and fall of solar use were fuel shortages, desire for convenience, and economic incentives. Resulting use varied from all levels of a community to only the elite.

**Diffusion of Innovations**

After oil price increases in 1973 and in 1979 the United States government began to look seriously at promoting alternative energy sources such as solar energy. It initiated tax incentives for solar users, grants, and various projects to show how beneficial solar energy is to homeowners. In other words, it tried to accelerate the diffusion of "new" solar technologies, or at least the idea that the sun is a valuable resource which can be utilized.

There are many ways to look at the diffusion or the spread of something. Diffusion of innovations research has been conducted mainly by geographers and sociologists. Hagerstrand initiated much thought in this area by stressing not only distance, but the role of information and communication in predicting the spread or diffusion of an innovation (Mitchell, 1989). Other perspectives on diffusion followed and have been separated into four categories by Lawrence Brown: the economic history
perspective, the development perspective, the adoption perspective, and the market and infrastructure perspective (Warkov and Meyer, 1982). These categories are used to illustrate the different issues involved in the diffusion of solar technology.

The economic history perspective focuses on how innovations change over time to better incorporate what potential adopters need or want. This is a function of the interrelationship of society and economy (Warkov and Meyer, 1982). For instance, the amount to which solar is used in the household or in industry has been affected by where federal research money has been spent and what users have demanded.

The development perspective looks at how the diffusion of something causes other social and economic changes. Looking at solar diffusion to discover what impact it has had can be useful in allowing people to take measures to avoid unpleasant impacts. For example, people with more money may buy solar and in turn save money on energy which serves to broaden the gap between people of different economic levels.

The adoption perspective focuses on the process of innovation acceptance. What causes people to adopt an innovation and when does this occur. Common themes of the adoption perspective include perception of the innovation, characteristics of early adopters versus later adopters, and
the role of the availability of information about the innovation (Warkov and Meyer, 1982).

The market and infrastructure perspective examines how innovations are delivered to society so that adoption can occur. Manufacturers, dealers, and installers with assistance from government programs make solar available to the public (Warkov and Meyer, 1982). Some aspects of the market and infrastructure perspective rely on the adoption perspective. Deciding where to have dealers and manufacturers, and where to direct advertising, is dependent on assumption about the market (Heiko, 1979).

Each of these diffusion perspectives offer a different way of looking at the solar use issue. Each makes apparent the problems and benefits of various solar promoting strategies. Concepts which are helpful in viewing different strategies under all of the diffusion perspectives are barriers and incentives. Barriers are those things which limit or impede use of an innovation. Incentives are those things which encourage use of an innovation by reducing the barriers (Warkov and Meyer, 1982).

**Barriers**

Barriers to residential solar energy use have been identified and studied by many people including Broda (1984), Durham et al (1988), Farhar-Pilgrim and Unseld (1982), Fry
(1986), Heiko (1979), McDaniel (1983), Mitchell and Bennett (1986), Warkov (1983), Warkov and Monnier (1985), and Wayne et al (1986). As a basic framework for looking at barriers to residential solar energy use, I have separated them into three categories: physical, economic, and social. These are not exclusive categories and indeed can affect one another.

Physical barriers are those which restrict resource availability or utility. They can be restrictive amounts of direct and diffuse sunlight, limited access to sunlight due to objects being between the house and the sun, limitations of the solar equipment to convert solar energy into useful energy or work, the limited supply of the solar equipment available for purchase, or the lack of skilled laborers to maintain the system. Physical barriers result in economic and social barriers by increasing the cost of the solar systems, or causing people to perceive solar as not being feasible.

Economic barriers are those which affect homeowner ability to afford solar energy systems. These are expensive initial cost for equipment, high cost of maintenance, the relatively inexpensive cost of other fuel sources and their equipment to the homeowner, and high interest rates. As the combination of these factors causes the payback period to increase, fewer people will invest in solar energy systems.

Social barriers are those attitudes, characteristics,
or perceptions that individuals, communities, or the culture have which restrict people's desire, or willingness, to adopt solar technologies. Some common social barriers are the perception that there isn't enough sun, that the present technology can't fulfill needs, or systems are too expensive. Social barriers may be the most challenging to overcome.

**Incentives**

Physical Factors

*It is clear that a great deal of solar energy bombards the earth but it is not clear how much can be utilized effectively and without consequences. Each year 40,000 kilowatts of solar energy per person falls upon the earth. Of this, .1% is used for photosynthesis (Broda, 1984). However, the dispersal of solar energy on the earth's surface is not uniform. Areas such as Southern California receive much more direct sunlight than areas such as the Pacific Northwest (see figure 3). Consequently, solar designs for space heating and water heating have to be site specific and the costs of such systems vary greatly from one region to the next. People have taken advantage of his abundant "free" energy by using it to heat their homes and their water. It*
FIGURE 3. Mean daily total horizontal solar radiation in June and December (Wayne et al., 1986, 292-293).
is estimated that passive solar designs can supply 40-80% of the heating energy even in less favorable solar climates (Wayne, Hall, and Behler, 1986). An active or combined active and passive system could supply 100% of the heat needed, however, it would be very large and expensive. So, usually a conventional electric back up system is also installed (Mitchell and Bennett, 1986 and McDaniel, 1983). Conventional back up systems take away many of the perceived limitations of solar heating systems. However, the overall system is more expensive to buy than a conventional system.

After considering how well the technology works in a particular climate one is faced with more site specific physical barriers. Sunlight can be blocked by buildings, vegetation, or topography. Solar orientation and solar devices don't do much without sunlight. To insure that sunlight will be available to homeowners, state and local governments have passed solar access laws or ordinances.

The four main types of solar access legislation in the United States are subdivision regulations, zoning, volunteer easements, and right to light or nuisance laws. Subdivision regulations are directed at lot and building orientations in new subdivisions. Zoning ordinances limit building and vegetation height and designate set back requirements. Voluntary easements allow neighbors to set up easements between properties that protect the right to sunlight. Right to light and nuisance laws protect existing access to sunlight.
Solar access laws have varying success. Fleitell (1987) evaluated ordinances in eighteen cities and found that the most specific and comprehensive ordinances were the most effective though they had a higher learning curve. Voluntary easements though very easy to use are hardly ever implemented. Bradbrook (1988) argued that local planning laws are better than state laws, because they can be tailored to the local conditions. In the Pacific Northwest, Kale (1989a and 1989b) evaluated local ordinances and estimated a 10-20% electricity savings by having solar ordinances in place before construction. Kale also estimated the costs of ordinances to be less than that of conservation measures. Assuring homeowners continued sunlight will improve solar effectiveness as well as take away possible solar user's doubts that they could lose their investment by a blocked sun.

Economic Factors

Future expectations of economic gain or loss are the basis for economic theories that attempt to explain human behavior (Warkov, 1983). The factors directly influencing solar economics are tax savings, energy prices, and climate (Fry, 1986). So, the adoption of solar will depend on the current energy prices, the tax credits available and the climatic conditions where the home is located.
After the oil price shock in the early 1970's, the United States government began to look seriously at promoting alternative energy sources. In 1977 residential energy income tax credits were established covering a portion of the cost of solar water and space heating equipment (Durham, Colby, and Longstreth, 1988). By 1981, 40 states were offering financial incentives for the adoption of residential solar technologies (Olson, 1981 in Durham, Colby, and Longstreth, 1988).

Taking into consideration federal and state financial incentives, solar radiation availability, equipment prices, and current fuel prices, solar heating systems would be economical in most states over a ten year period. If only five years were considered, states having exceptional solar radiation, or very high state tax incentives such as Colorado and Kansas, would be economical where in most states solar heating would not be economical (McDaniel, 1983). Whether or not it is considered economical depends largely on how long a pay back period is involved.

The length of the pay back period can be a real problem in the residential United States, because the society as a whole is very mobile. "The U.S. Bureau of Labor Statistics has estimated that 20% of the population moves every year" (McDaniel, 1983, 70). If people do not stay in their homes for more that 10 years it may not be economically advantageous for them to invest in a solar heating system.
Also, builders will choose the lower initial investment because they will be able to list the house at a lower price (Fry, 1986). A mobile household will tend to buy the lower priced house.

Other problems in the economics of residential solar heating systems are that from household to household heating needs vary and the value of the tax credit varies (Fry, 1986). Income tax credits will allow people with higher incomes to get more money taken off their taxes. Since tax credits are taken off of the amount of tax the individual owes, if the individual does not make much and does not owe much, less can be claimed. Also, if a household does not have many heating needs, the pay back period for the initial solar investment will be very long.

So far we have been assuming the price of solar equipment to be fairly constant in a particular place. In general this is true, but the price at a particular place is dependent on the state tax incentives available. Solar equipment costs less where tax credits are less and costs more where tax credits are more (Fry, 1986). This way the solar company can gain from the tax incentives, too. They are not increased to the point that the tax incentives are completely invalidated, though. If the state tax incentives were to be eliminated, in some areas the solar heating system would still be economical because the equipment prices would decrease.
The economic feasibility of solar heating systems is based on a comparison with prices of electric energy and natural gas. These prices in turn are largely determined by Federal assistance. Fossil and nuclear fuels get considerably more federal assistance than solar energy (McDaniel, 1983). Actually, the amount spent on solar energy research is less than 10% that of nuclear energy (Broda, 1984). Broda (1984) suggested that this may be because solar energy materials, instruments, and skills are not useful in war and defense. Furthermore, federal subsidies are given for new power plants and research. If electricity prices reflected the cost of the power plants without federal subsidies and solar energy users were given tax benefits, solar energy would heat water cheaper than electricity in many cases (Fry, 1986). The federal government has a lot of power to control the economic advantage of residential solar power by issuing federal income tax incentives, and having a controlling hand in the price of other energy sources.

Yet, what does an economic advantage mean? Will people automatically adopt solar if the price is right? As was noted in early California, Greek, and Roman history an extreme price difference between solar versus other fuels can induce changes. However, the examples also show that the amount and type of change can vary significantly. For example, in Greece a community wide strategy was taken in
implementing solar in the average household. Whereas in Rome solar was adopted mainly by the rich but was also used in public bath houses. In California solar was initially being adopted by average homeowners as a superior technology but was later successfully defeated by a gas company that targeted all homeowners with huge financial incentives. Cultural differences such as political ideology, social class structure, and market structures may play a role in the different outcomes.

Social Factors

Still, the social factors are not recognized as a possibility by many researchers. They assume that economic factors play the key role. Contrarily, Workov and Monnier (1985) pointed out that although 75% of the United States homeowners could not tell how much solar energy equipment costs, they would pick it out on a questionnaire as a major deterring factor. Workov and Monnier (1985) also noted that in the open interviews that French researchers employed, people did not mention economic factors. So, the method used and the results obtained are connected in some way. Questionnaires and interviews must be designed without the researchers' bias leading people to specific answers.

In the studies that stress the social aspects as being influential in the adoption of residential solar energy,
level of education, amount of social encouragement, and perception of a problem, are considered to be important factors.

Most agreed that the higher the education the more likely people were to adopt solar (Warkov, 1983; Warkov and Monnier, 1985). Yet, the level of education may be dependent on other factors such as the amount of money one has available for educational expenses. Also, more educated people tend to be wealthier, so they can afford solar technologies, whereas, poorer less educated people could not afford solar technologies. Still, if people knew more about solar energy, maybe they would be less afraid of a "new thing" and more likely to give it a try.

The amount of social encouragement that is received may also affect adoption. It may be that individuals need approval from others, or peer pressure, to influence them to adopt. Warkov (1983) found that the amount of encouragement was related to the perceived personal benefits. It is not clear whether people that perceived personal benefits about solar adoption then sought encouragement and approval for their actions, or if encouragement influenced them into perceiving personal benefits (Warkov, 1983).

Other aspects may be perceived differently by adopters and non-adopters. One that is brought up continuously in research, is how people perceive the future. More specifically, will there be an energy shortage problem in
the future? Warkov (1983, 135) in studying solar adopters and non-adopters in Connecticut found that 70% of solar adopters believed that "the world in running out of fossil fuel supplies" and only 46% of the non-adopters believed this.

Warkov (1983) acknowledged that future expectations are related to people's past experiences, their view of the present situation, and their orientation toward time. Are they future oriented, past oriented or present oriented? These in turn are culturally determined and will change from one culture to another. Warkov did not try to assess these aspects, or try to determine why people viewed the future of fuel supplies differently. He did conclude, however, that fear may be needed as a final push for people to take the economic benefits of tax credits, loans, and grants and then adopt solar technologies.

On the other hand, Farhar-Pilgrim and Unseld (1982), found that "fear is not a strong motivation for solar energy." They concluded that solar adopters were optimistic about the future energy situation and that people with pessimistic views tended not to adopt solar energy. The differences in the two studies may result from the method of the research and interpretation of the findings.

Warkov (1983) asked whether people believed there will be a fossil fuel shortage and did not consider whether or not they perceived this to be a real problem. On the other hand, Farhar-Pilgrim and Unseld looked at whether
people were optimistic or pessimistic about the future energy situation and concluded that adopters view future energy problems as something that is solvable and would not be a real problem. Another factor that could have affected the different results is that Farhar-Pilgrim and Unseld surveyed nation-wide and Warkov's study was exclusively in Connecticut where specific future perceptions may persist. Cultural variations and the social networks present, may also influence whether or not a home-owner adopts solar energy. If people perceive positive governmental and social positions toward solar energy they are more likely to adopt (Farhar-Pilgrim and Unseld, 1982). People may also be supportive of adoption if it is compatible with their culture (Warkov and Monnier, 1989). These social networks can be very supportive to the adoption of solar energy.

Discussion

Residential solar energy use has varied in type and extent throughout time. Availability of other energy resources has played a major part in stimulating major fluctuations in the solar market. Other physical, economic, and social barriers have effected the diffusion or adoption pattern in specific regions and classes of people. If more use of residential solar energy is desired in our society, these barriers must be overcome in a way that encourages
everyone, everywhere, to adopt to the extent that it fulfills their needs.

Incentives are used to combat barriers. Tax incentives have increased adoption rates in some states. However, they tend to favor wealthier homeowners. Other economic incentives such as grants and low interest loans might attract additional users. Also, reduced federal subsidies for other energy sources would clearly decrease the economic barriers as well as provide a government encouragement for solar. This act would serve to decrease social barriers as well by stressing the concerns of oil dependency and giving people more confidence in solar.

Increasing funding of research and development would not only serve to improve the physical benefit of the technology, but would again stress to people that solar is worth spending money on. Another proven way to combat the physical barriers is to develop comprehensive solar access laws within individual communities.

When developing incentives it is important to pay attention to the cultural make up, political ideology, economic structure, and physical characteristics present. The diversity of climatic, physical, and cultural characteristics in the United States will require a combination of strategies to be used. It is also important to consider changing strategies over time. Different types of people buy solar for different reasons as the market
Market Development Over Time

percent purchasing per unit time

a. Innovators - risk takers, financially secure, understand technology
b. Early Purchasers - opinion leaders, selective
c. Early Majority - (require time to consider new purchase)
d. Late Majority - (need to see that the product is commonly purchased)
e. Laggards - (tend to be suspicious of new products)

Figure 4 (Meiko, 1979)
develops (see figure 4) (Heiko, 1979). First, it might be easiest to target higher income people who are willing to risk money for other concerns. Stressing oil dependency, environmental concerns, and the newness of a particular solar design might be beneficial at this point. As the market matures a change in strategies towards increasing financial incentives to lower income people and beginning an educational program that would show how well solar is working for others in a similar environment. Solar access strategies would be most beneficial if implemented before a majority of people had purchased.

As oil supplies diminish, and environmental concerns about other fuel sources heighten, changes will occur. There will likely be an increased interest in solar. How and to what extent solar energy is incorporated into homes will largely depend on what strategies are used to encourage it. Many of the strategies presented require some form of government support. For good, or bad, in the United States, the majority of people don't have to believe in something for it to be supported by the government. A few outspoken people with some financial backing can create enough concern for changes to be made.
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