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Solar Radiation Resource Assessment— An Overview

Introduction

The Earth receives a vast amount of energy from the sun in the form of solar energy, or solar radiation. A variety of solar energy conversion technologies are being developed to tap this energy source and give us environmentally acceptable alternatives for our heating, cooling, electricity, and transportation needs. Technologies for converting solar radiation into usable forms of energy include the following:

- Solar electric (photovoltaic) technologies, which convert solar radiation directly into electricity
- Solar heat (thermal) technologies, which convert solar radiation into heat
- Solar heat-electric technologies, which convert solar radiation into heat to generate electricity
- Solar fuels, in which photosynthesis operates to produce biomass (such as energy crops) that can be converted into fuels and energy products
- Passive solar technologies, in which solar radiation is used directly for daylighting and controlling the environment of buildings.

Generating usable energy with these solar energy conversion technologies depends critically on the amount of solar radiation available to these technologies in a given area. This available solar radiation, which varies in different climates and locations, is called the solar resource. To select and design the best energy-conversion technology for a given area, we have a basic need to measure and understand the nature of the solar resource in many different areas. Therefore, the Solar Radiation Resource Assessment Project was established at the Solar Energy Research Institute (SERI) to help develop a comprehensive base of information on the solar radiation resource and an in-depth understanding of it.

In this overview, we describe the basics of solar radiation resource assessment, why it is important, SERI's Solar Radiation Resource Assessment Project, and recent as well as proposed project activities.

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Why Is Solar Radiation Resource Assessment Important?

The cost and reliability of energy production are two factors that are important to building owners, the public, private businesses, and utilities in considering whether to use solar energy conversion technologies. Uncertainties about the solar radiation resource result in uncertainties about the amount and cost of energy production with a given technology. But if the solar radiation resource for a given area is well known, a solar-based technology can be selected for optimum performance in that area. Variations in the resource can be anticipated, and energy delivery costs will be lower.

In other words, we need information about the solar radiation resource to make decisions that will determine the cost and reliability of an energy-conversion system. The kinds of information we need are illustrated in the following questions.

- Considering the variations in solar radiation from one geographical area to another, what is the best location for the solar energy conversion system we have selected?
- Considering the amount of the hourly, daily, or seasonal solar resource at a particular location, how large should a system be to produce the energy needed at minimum cost?
- Considering the hourly, daily, or seasonal variations in solar radiation at a particular location, how much will the solar energy system output vary over a day, a month, a season, or a year?
- Considering hourly and daily variations in solar radiation at the location, how much energy storage

or backup capacity is needed to make sure we have energy when we need it?

- Considering the daily profile of solar radiation for the location, is there a match between peak energy load demands and the maximum solar radiation available (also known as the peak load shaving potential)?

We must also consider some specific characteristics of the solar resource related to particular solar energy conversion technologies. For example, knowing the wavelength or spectral distribution of solar radiation is important in predicting the energy output of solar (photovoltaic) cells, which have specific spectral responses. The intermittent nature of solar radiation on partly cloudy days is also important to know, if we are to predict the energy output of solar thermal systems that require a certain minimum intensity level of solar radiation to begin

Determining Solar Energy System Performance and Energy Costs

The cost of energy or power produced by a solar energy conversion system is proportional to the amount of solar radiation that is utilized over the lifetime of the system. In simple terms,

$$\frac{\text{Energy Cost}}{\text{Energy (System) Output}} = \frac{\text{System Cost}}{\text{Solar Energy Input} \times \text{System Efficiency (Solar Radiation)}}$$

This relationship shows that if our solar radiation estimates are uncertain, the system's energy output and energy costs will be uncertain. Therefore, it is important that solar radiation values be as accurate as possible so that we may predict system output and energy costs reliably.

Defining the solar resource for different locations is a challenge because the atmosphere is very dynamic.

operating and a certain ramp-up time to reach full power. We might ask, "What kind of photovoltaic or thermal system will work best, given the spectral and intermittent characteristics of the solar resource at this site?"

It isn't enough, though, to measure solar radiation at a particular place for a short period of time (say, one year) to answer these questions. One year's conditions may not represent a climate's general variability. If the design for a solar energy conversion system is based on a "sunny year" at a certain location, it will not produce the amount of energy we expect during a "cloudy year." Long-term records of solar radiation are needed to account for seasonal and longer term variability and changes in climates. So, we also need to ask about the nature of the solar resource at a site over a considerable period of time.

The Solar Radiation Resource Assessment Project at SERI is gathering and developing these kinds of information to help people answer these kinds of questions. The goal of the project is to help meet the needs of the public, the government, industry, utilities, and researchers for solar radiation resource assessments they can use to develop, design, build, and operate solar energy conversion systems.

Understanding the Basics

About Solar Radiation

Solar radiation is a general term for the visible and near-visible (ultraviolet and near-infrared) electromagnetic radiation that is emitted by the sun. It has a spectral, or wavelength, distribution that corresponds to different energy levels; short-wavelength radiation has a higher energy than long-wavelength radiation. The different regions of the solar spectrum are described by their wavelength range. The visible region extends from about 390 to 780 nanometers (nm).^{*} About 99% of solar radiation is contained in a wavelength region from 300 nm (ultraviolet) to 3000 nm (near-infrared). The combined radiation in the wavelength region from 280 nm to 4000 nm is called the broadband, or total, solar radiation.

Outside the Earth's atmosphere, the amount of solar radiation is nearly constant, with an average intensity of 1367 watts per square meter (W/m^2). Variations of about $\pm 3\%$ in this value are caused by the elliptical orbit of the Earth around the sun and such solar activity as sun spots. However, the amount of solar radiation reaching the Earth's surface varies greatly because of changing atmospheric conditions (such as cloudiness) and the changing position of the sun in the sky, both during the day and throughout the year.

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Extraterrestrial Spectral Solar Radiation

The electromagnetic spectrum

^{*} 1 nm is 10^{-9} meters (m) in length, or one billionth of 1 m.

Some of the solar radiation entering the Earth's atmosphere is absorbed and scattered by it. The sum of the direct beam and diffuse radiation that arrives at the surface is called global solar radiation.

When solar radiation enters the atmosphere, it is absorbed and scattered by such atmospheric constituents as air molecules, aerosols, water vapor, and clouds. Solar radiation that reaches the Earth's surface directly from the sun's disk (that is, not scattered or absorbed) is called direct-beam solar radiation. The radiation

that has been scattered out of the direct beam by molecules, aerosols, and clouds is called diffuse (or sky) solar radiation. The sum of direct and diffuse radiation in a hemisphere of the sky is called global solar radiation.

Different solar collectors are configured to use different components of the solar radiation available at particular sites. For example, concentrating collectors focus direct-beam solar radiation from the solar disk, and a fraction of the forward-scattered radiation around the solar disk called circumsolar radiation, onto the collector. When the collector is directly facing the sun, and direct-beam radiation strikes the surface at an incidence angle equal to zero, it is receiving direct-normal radiation. (The incidence angle is the angle between the sun's rays and a line perpendicular to the collector's surface; see the illustration at left.) A flat-plate solar collector that is tilted toward the equator makes use of the direct-beam radiation that strikes the collector's surface at various angles throughout the day, as well as scattered or diffuse sky radiation and even radiation reflected from the ground. Flat-plate collectors can be mounted on solar trackers that follow the sun, so that the direct-beam component will strike the collectors at a near-zero or low incidence angle throughout the day.

Incidence angle directly affects energy intensity. The compact dot pattern on the left shows what happens when the sun's rays are perpendicular, or normal, to the collector's surface (incidence angle = 0°). The spread-out dot pattern on the right shows what happens when we increase the angle of incidence and the rays strike the surface at an angle. This illustration shows that facing our collector directly toward the sun allows us to collect more intense energy.

Atmospheric conditions affect the relative amounts of direct and diffuse solar radiation available at a site. The portion of total solar radiation that is diffuse ranges from about 10% to 20% in clear skies to 100% in cloudy skies. It is important to characterize solar

radiation components (direct, diffuse, ground-reflected, etc.) separately because they have different magnitudes and spectral distributions. And different solar devices and systems make use of different amounts of these components of solar radiation. Thus, we must break down the solar resource by its components to be able to predict the performance of different solar collectors.

About Resource Assessment

Although solar radiation is available all over the Earth, the specific amounts that are available and the characteristics of the resource vary significantly from one location to another. The spatial distribution of this resource can be mapped, just as other energy resources, like gas and oil, are. However, because solar radiation is a weather-related variable that changes throughout a day and a season, we must document temporal as well as spatial distributions. An additional characteristic that is important for spectrally selective solar energy conversion systems such as solar cells is the spectral variability of the resource. Other basic concerns are the period of record, definitions of the fundamental data needed, and the accuracy of the data.

Spatial (geographic) variability

Adequately defining the geographic distribution of the solar resource across the United States requires at least several hundred measurement stations. This is because the solar radiation resource can change in a short

Concentrator collectors (top) make use of direct-beam solar radiation from the solar disk; flat-plate collectors (bottom) make use of both direct-beam radiation and diffuse (sky) radiation.

(a) These maps show how the distribution of annual averages of daily solar radiation data varies across the United States for different solar-radiation components. This map (a) shows direct-beam solar radiation on a collector that tracks the sun's disk (direct-normal, the resource used by concentrator collectors). The two smaller maps show (b) global solar radiation on a horizontal surface (the

resource used by energy crops, solar ponds, etc.), and (c) global solar radiation on a south-facing surface tilted at the latitude angle (the resource used by photovoltaic collectors tilted at an angle from the horizontal that is equal to the site's latitude). (Note: Numbers on map (a) are MJ/m²; multiply by 0.277 to obtain kWh/m².)

distance. For example, from the plains and foothills adjacent to the Rocky Mountains to the mountain locations only 100 kilometers away, there is a significant difference in the solar resource. Solar radiation data may also be relatively constant for several hundred kilometers, as in the Great Plains. Because of budget limitations, the current number of long-term radiation monitoring stations in the U.S. national

solar radiation network, which is operated by the government, is about 30. These are operated by the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA). A limited number of regional measurement networks have also been operated by universities and by electric utilities. When measured solar radiation data are not available for a certain site,

(b)

(c)

techniques such as computer modeling are used to estimate the resource.

Temporal variability

Probably the most common criticism of using solar radiation as an energy source is that it is intermittent, which supposedly makes it unreliable and difficult to manage. One of the most frequent questions posed by a potential customer is, "Will the solar energy system deliver energy when I need it?" This is where resource assessment is extremely important.

Having a thorough understanding of the temporal character of solar radiation is critical to ensuring that the output of a solar power plant matches a particular energy load demand.

A case in point is the potential use of solar electric plants to provide the additional electricity needed to meet afternoon air-conditioning loads. Hourly and daily profiles of solar radiation are vital to knowing when and how long a solar energy conversion system will be on line or off line. This information also tells us how much storage capacity is required and whether we can expect the resource to be available during peak demand hours. Adequate information on the temporal variability of the resource helps ensure that solar power generators can be suitably designed and managed.

Spectral variability

The amount of scattering and absorption of solar radiation by such atmospheric constituents as air molecules, aerosols, and water vapor varies with the wavelength of the radiation. For example, molecular (Rayleigh) scattering is stronger in the short wavelengths of the ultraviolet (below 390 nm) and visible (390-780 nm) regions of the spectrum than it is in the near-infrared region (beyond 780 nm). The scattering and absorption effects of aerosols depend on their composition and their size relative to the wavelength of the radiation. Spectral variations due to water-vapor absorption are greatest in certain wavelength bands, such as those around 940 nm.

Because of the spectral dependence of scattering and absorption processes, the spectral distribution of solar radiation changes with different atmospheric conditions and with air mass. Fairly complex instruments called spectroradiometers are used to measure spectral solar radiation. From these measurements, models are developed that predict the spectral distribution from meteorological data and air-mass values. These models are needed to estimate spectral solar radiation resources for areas where actual data are not available.

Period of record

Climatology experts have agreed that a 30-year period of data collection is required to establish the norm (average) and the natural variability (high and low values) of a weather variable, such as temperature. This is also true of a weather-related variable such as solar radiation. In addition, the 30-year record should be updated every five years to account for changes in solar radiation due to climate changes. Therefore, long-term, continuous measurements of solar radiation are necessary to document variability and keep information up to date.

Fundamental data

It is usually impractical to measure solar radiation values for all possible solar collector types and orientations. The common approach is to provide a fundamental data base for direct-beam and global-horizontal solar radiation and to rely on mathematical models to convert these components to the solar radiation incident on a collector's surface. The most common solar radiation

measurement is global-horizontal, so models are often needed to estimate direct-beam and diffuse radiation as well. If there are no measurements of any solar radiation components for a particular area, they must be estimated with models that relate solar radiation to such meteorological variables as cloudiness. To develop and validate these models, we need research-quality data bases that include both solar radiation and meteorological data for a variety of climatic conditions.

Accuracy

Another very basic concern is how accurate the solar radiation data must be. Most experts agree that the data should be accurate to within 5%. This requirement is based on an engineering goal of being able to predict delivered energy to within $\pm 5\%$ and being able to specify the total area of collectors and their costs to within $\pm 5\%$ of what is needed to meet a specified output, or delivered energy.

Reaching this accuracy goal is not as straightforward a task as it may seem. For a data base to reflect the true natural variations in solar radiation, the uncertainties in the data must be much smaller than the degree of natural variability. If the uncertainties in the data are too large, this natural variability will not be detected. Whereas average annual variations may approach 10% to 20% at a given site, the seasonal, monthly, and daily variations can be much larger; furthermore, direct-beam variations are greater than global-horizontal variations at the same site. As one would expect, the natural variability of solar

A pyranometer is used to measure solar radiation from the entire sky hemisphere (top); It can be shaded from the solar disk to measure only the diffuse radiation (bottom left). A pyrhemometer is used to measure solar radiation from the sun's disk by tracking the sun and limiting the instrument's field of view (bottom right).

Understanding Seasonal and Atmospheric Variations

The elevation of the sun from the horizon, or, conversely, the angle of the sun from the vertical (straight up, or zenith) determines what is called air mass. Air-mass values are higher when the sun is lower in the sky. For example, air mass is 1 when the sun is directly overhead and the angle of the sun from the zenith direction is 0° , and 2 when the angle is 60° . The air-mass value at any particular time depends on the location (latitude), the time of day, and the day of the year.

When the sun is closer to the horizon, direct-beam radiation must pass through a longer distance in the Earth's atmosphere than when it is overhead. This longer path length results in both more scattering and more absorption of the solar radiation.

The atmosphere through which the solar radiation passes is also quite variable. Significant variables are atmospheric turbidity (haziness due to aerosols), precipitable water vapor, and clouds. So, what exactly is the atmosphere's effect on solar radiation? It basically acts as a dynamic

filter, absorbing and scattering solar radiation. It creates spatial (geographic), temporal (hourly, daily), and spectral variations in solar radiation that we must characterize or describe with respect to their effects on operating solar energy conversion systems.

radiation is strongly dependent on the specific climate at a given site.

Comprehensive solar radiation resource assessment involves all these considerations—the spatial, temporal, and spectral variations in the resource as well as appropriate periods of

record, fundamental data, and accuracy. The purpose of solar radiation resource assessment is to characterize and quantify natural resource variations so that solar energy conversion systems can be designed, located, and operated properly and reliably.

The Solar Radiation Resource Assessment Project

The Department of Energy's (DOE's) Solar Radiation Resource Assessment Project at SERI helps to meet the needs of industry, utilities, researchers, and the government for solar radiation data, models, and assessments. These are required to develop, design, deploy, and operate solar energy conversion systems. The scope of SERI's Solar Radiation Resource Assessment Project ranges from defining the natural (e.g., spatial, temporal, and spectral) characteristics of the solar resource to quantifying its availability at a specific location.

The need for this resource information cuts across many solar technologies to cover a wide variety of users. The project evaluates needs for information by interacting directly with DOE, industry, and utilities at conferences and other special meetings. The project is reviewed and guided by a Science and Technology Review Committee, a group comprising representatives from universities, government, and utilities, to help keep the program technically sound and relevant to users' needs.

After identifying these specific needs, the staff members of the Solar Radiation Resource Assessment Project determine common needs that can be addressed for a large number of users at a minimal cost. These common needs include the following:

- Long-term data bases that facilitate system design by representing the natural variability of solar radiation
- Continuous, reliable measurements of solar radiation from a network of sites in the United States
- Solar radiation availability maps, data, and resource characterizations covering the United States for various types of solar collectors
- Spectral solar radiation models and data bases needed in the design and development of spectrally selective solar energy conversion systems
- Representative, or typical, solar radiation data sets (e.g., typical year) that can be used in economic comparisons of systems
- Methods of estimating site-specific solar radiation that can be used in selecting optimum sites and site-specific designs and in predicting the performance of various systems
- Models or algorithms that convert solar radiation data from one component to another (e.g., from global-horizontal to direct and diffuse solar radiation on a surface of any orientation)
- Quality assessment methods for evaluating measured data
- Instruments and methods that measure the solar radiation resource accurately and that evaluate the performance of a solar energy conversion system reliably
- Worldwide solar radiation resource assessments that will help to evaluate market potentials for U.S. industries.

All of these broad categories take into consideration the spatial, temporal, and spectral characteristics of the solar resource, the period of record needed, and the accuracy or uncertainty associated with the radiation data.

The Solar Radiation Research Laboratories

SERI's laboratories enable researchers to obtain research measurements, develop models, and investigate resource assessment methods. The Solar Radiation Research Laboratory acquires basic solar radiation and meteorological data to support outdoor experiments, develop measurement techniques, and calibrate solar radiation instruments. A wide range of solar radiation measurement instrumentation is maintained, along with reference instruments for measurement traceability to national and international standards. These instruments include pyranometers for measuring global and diffuse solar radiation, pyrhemimeters for measuring direct-normal solar radiation, spectroradiometers for measuring spectral solar radiation, and cavity radiometers for precisely measuring direct-normal solar radiation during instrument calibration. SERI's computer data processing laboratory is used to archive and process great quantities of solar radiation data and to develop resource assessment methods that make use of computer mapping.

The Solar Radiation Resource Assessment Project has identified several high-priority activities. The first is to produce a 1961-1990 solar radiation data base for the United States to replace the 1952-1975 data base. The latter data base contains hourly global horizontal solar radiation data measured by NOAA-NWS at 26 sites across the United States from 1952 to 1975 (called SOLMET). It also contains data for 222 additional sites that were estimated from SOLMET data (called ERSATZ) and estimated

direct-normal data for all of the SOLMET and some of the ERSATZ sites.

The new data base is needed for two reasons. The first is that an update is needed to account for climatological variations and changes. The second is that we can significantly reduce the possibility of errors by using improved models and more current data. The 30-year period of record is consistent with the World Meteorological Organization's standard practice of

SOLRAD, the national solar radiation measurement network, is operated by the National Weather Service within the National Oceanic and Atmospheric Administration. Data are collected at 31 locations across the United States and are sent to the National Climatic Data Center for archiving. SERI is using these data to produce a 1961-1990 national solar radiation data base.

using 30-year reference periods for climate statistics, one of which is the 1961-1990 time period. When it is completed, the new data base will be transferred to NOAA's National Climatic Data Center (NCDC) for dissemination to those who need it.

Another high-priority activity is to obtain high-quality, measured solar radiation data for the United States so that the national data base can be updated at five-year intervals. SERI has established an active, cooperative relationship with NOAA to help ensure the productivity of the current NOAA-SOLRAD national solar radiation network. NOAA is completing an upgrade of the network, operating the stations to collect data, processing the data, and sending the data to the National Climatic Data Center for archiving. SERI and NOAA work together to calibrate the network instruments regularly and to incorporate quality-assurance procedures.

In addition to the SOLRAD data, SERI obtains other high-quality solar

SERI's Solar Radiation Resource Assessment Project operates solar radiation measurement stations at six Historically Black Colleges and Universities in the southeastern United States.

radiation data whenever possible. For example, SERI operates six measurement stations at selected Historically Black Colleges and Universities (HBCU) to obtain solar radiation data in the southeastern United States, where the SOLRAD data are sparse. At the end of 1989, about 300 station-months of data had been collected, with an excellent data recovery rate of 96%-100%.

A third high-priority activity is to develop data bases and models of spectral solar radiation, which are necessary in designing and evaluating the performance of spectrally selective solar devices such as photovoltaic cells. The goals are to produce a research-quality spectral solar radiation data base and to develop spectral solar radiation simulation models for all meteorological conditions and wavelengths from 290 to 3000 nm.

The current spectral data base at SERI contains measured data that are reasonably accurate from about 400 to 1100 nm. However, newer and better measurements are needed for the ultraviolet (below 400 nm) and near-infrared (beyond 1100 nm) regions of the spectrum, where some of the latest multilayer photovoltaic devices respond. This requires developing spectroradiometers for extended-wavelength measurements and models that extend current data to other wavelengths. The spectroradiometer measurements are also vital in characterizing the solar simulators used to test developments in various technologies.

SERI's spectral solar radiation model is available to aid in evaluating the performance of spectrally selective technologies by simulating their performance for a range of sun angles and clear-sky conditions. There is a need to extend the model's capabilities to other atmospheric conditions, such as cloudy or polluted skies, so that a full range of meteorological conditions can be examined. SERI's researchers maintain close contact with other laboratories whose main responsibility is to develop specialized spectral solar radiation models. For example, SERI uses the high-resolution (LOWTRAN) models developed by the Air Force Geophysics Laboratory to develop new models that apply to solar energy conversion. High-quality, extended-wavelength spectroradiometer measurements are necessary to verify and validate these models.

A high-priority research project that should continue to receive attention is that of developing methods to estimate the solar radiation resource for areas where no data exist. This is critically important to the development of future sites for solar energy conversion systems. The research involves developing spatial interpolation techniques, such as mapping solar radiation using cloud-cover information from satellites, to estimate solar radiation between the measurement stations. It also involves developing computer models that use commonly measured meteorological data to estimate solar radiation in areas where no solar radiation measurements are available.

For now, the Solar Radiation Resource Assessment Project at SERI must focus its resources on high-priority areas, such as creating the 1961-1990 data base. Still, project scientists maintain limited involvement in activities that are specifically involved with spatial interpolation and extrapolation techniques, such as the International Energy Agency's Subtask 9D, "Techniques for Supplementing Network Data for Solar Energy Applications."

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Solar Radiation Resource Assessment Project staff have used several spectroradiometers to collect more than 3000 spectral solar radiation data sets for different atmospheric conditions and air masses. These data are used in studies of natural outdoor spectral variations and in the development of spectral models.

Future Activities

As the new, national solar radiation data base for 1961-1990 becomes available, and as the national solar radiation monitoring network operations become more established, resource assessment activities can

be directed toward developing site-specific solar resource estimation methods and several additional data products. The next step will be to develop long-term design data sets and representative, or typical, data sets for various sites and to produce maps and data sets that provide a statistical description of the spatial, temporal, and spectral

distribution of solar radiation over the United States.

Continuous, high-quality measurements of solar radiation at network stations are very important if we are to update the national data base every five years or so and account for any changes in climate. The Solar Radiation Resource Assessment Project has a strong interest in the viability of long-term networks operated by NOAA and others. The project provides cooperative support to these networks as much as possible to obtain data base updates.

The Solar Radiation Resource Assessment Project will maintain the Solar Radiation Research Laboratory to continue to develop solar radiation measurement instrumentation and

methods, perform outdoor instrument calibrations, and provide measurement support for outdoor experiments. The computer data-processing laboratory will be used to produce data sets and new solar radiation resource assessment products, such as maps, data summaries, and solar atlases.

The project's long-term goal is to provide solar radiation data and assessments and information on how to measure or estimate solar radiation for any site in the United States (and perhaps the world). Where measured values are not available, this information would take the form of reliable estimates from well-characterized models or interpolation methods. The models and interpolation methods would be able to make use of existing climatic data, such as cloud cover, to produce estimated broadband and spectral data.

The importance of solar radiation resource assessments is that they describe the natural variability of an intermittent resource that must be quantified and understood to successfully design and deploy solar energy conversion systems. A comprehensive understanding of the resource also allows us to recognize useful features that affect the economic viability of solar energy conversion systems, such as daily solar radiation profiles that suggest possible peak electricity load shaving. In its long-range plans, the Solar Radiation Resource Assessment Project seeks to anticipate and address solar radiation resource assessment needs in preparation for extensive deployment of solar energy conversion systems in the 1990s and beyond.

The solar resource

Appendix A

The Federal Role in Solar Radiation Resource Assessment

Significant federal activities in solar radiation resource assessment for energy development began as a result of the oil embargo of 1973. Before then, solar radiation was generally considered another climatic variable, significant only in the areas of meteorology, agriculture, and the environment. After the oil embargo, solar radiation was considered to be an important national energy resource. The Solar Energy Act, Public Law 93-473, Sec. 5, authorized a formal federal role in solar energy resource assessment. The act established "a solar energy resource determination and assessment program with the objective of making regional and national appraisal of all solar energy resources, including insolation,* wind, sea thermal gradients, and potential for photosynthetic conversion."

These specific goals for resource assessment were defined by the 93rd Congress:

- Develop better methods for predicting the availability of all energy resources over long periods and in different geographic locations.
- Develop advanced meteorological, oceanographic, and other instruments, methodologies, and procedures necessary to measure the quality and quantity of all solar resources on a periodic basis.
- Develop activities, arrangements, and procedures for collection, evaluation, and dissemination of information and data relating to solar energy resource assessment.

From 1973 to 1975, the National Science Foundation (NSF) was responsible for defining and coordinating federal solar radiation resource assessment efforts. This included a grant from the NSF to NOAA to help the NSF pursue these goals.

In January 1975, the Energy Research and Development Administration (ERDA) was formed, and it subsequently assumed the federal role for solar radiation resource assessment. Solar radiation assessment was part of a broader program called the Environmental and Resource Assessment Program. As part of this program, ERDA and NOAA signed an interagency agreement that established NOAA's role in solar radiation resource assessment. NOAA was funded by ERDA to establish a new, national solar radiation monitoring network, to correct previous NOAA-NWS data covering the 1952-1975

*Incident solar radiation.

period, to generate estimated values using models, and to produce and disseminate a national solar radiation data base.

In late 1977, ERDA became the Department of Energy. The formal line-item budget for the Environmental and Resource Assessment Program was continued for fiscal years (FY) 1977 and 1978. In FY 1979, the Environmental and Resource Assessment Program was discontinued as a line item in the DOE budget. At the same time, a semiformal DOE program, called the Insolation Resource Assessment Program (IRAP), was established to continue DOE solar radiation resource assessment efforts. DOE management responsibilities were assigned to the Division of Distributed Technology in the Photovoltaic Energy Systems Branch. Subsequently, DOE assigned technical guidance and day-to-day management responsibilities to SERI. Funding for IRAP was obtained from various DOE solar technology programs.

During early 1979, DOE and NOAA signed a letter of understanding stipulating that DOE would

- Fund the operation of the NOAA-NWS solar radiation monitoring network through 1980
- Support the NOAA budget request for FY 1981 and beyond
- Fund any special requirements beyond FY 1981
- Consult with NOAA on solar radiation monitoring matters in order to maximize benefits to the solar energy technology community.

NOAA agreed to request funds in FY 1981 and thereafter, to maintain and operate the solar radiation network, and to respond to proposals in support of other federal or nonfederal users of solar resources on the processing or forecasting of solar information.

The semiformal DOE-IRAP arrangement continued through FY 1980. The DOE Photovoltaics Program, along with other DOE technology programs, was able to provide funds for some solar radiation resource assessment activities. One of these activities was the establishment of a national laboratory capability at SERI.

In FY 1981, IRAP was essentially discontinued as a result of the sharp drop in the funding of all solar energy programs. Funding was obtained, mostly from the DOE Photovoltaics Program, to maintain a core national laboratory capability at SERI, to maintain the national solar radiation data bases, and to perform research in high-priority areas. This situation remained about the same through FY 1985.

In 1984, the House of Representatives Science and Technology Committee (through its subcommittee on Energy Development and Applications), the American Solar Energy Society, and SERI concluded that existing information and knowledge about solar radiation resources were not adequate to meet the needs of current solar technologies and future applications. An expanded and focused federal role was recommended. In FY 1986, the Resource Assessment Program and a line-item budget were established by Congress and assigned

to DOE. Subsequently, SERI was designated the DOE lead center for solar radiation resource assessment, and the Solar Radiation Resource Assessment Project was established.

Appendix B

U.S. Solar Radiation Data Sets

The following is a list of the current data sets on solar radiation for the United States. Brief descriptions of the data are also provided for each data base.

SOLMET

Hourly measured global-horizontal (rehabilitated) and modeled direct solar radiation data and meteorological data for 26 sites across the United States. (NCDC Tape Deck 9724)

ERSATZ

Hourly modeled global-horizontal solar radiation data and meteorological data for 222 sites across the United States. (NCDC Tape Deck 9724)

1977-1980 NOAA Solar Radiation Network Data

Hourly measured global-horizontal solar radiation data at 38 sites, direct solar radiation data at 32 sites, and diffuse-horizontal solar radiation data at 9 sites across the United States, collected from January 1977 to December 1980. (NCDC Tape Deck 9736)

Typical Meteorological Year (TMY) and ERSATZ Typical Meteorological Year (ETMY)

(NCDC Tape Deck 9734, 9 regions)

TMY: A subset of SOLMET data covering a one-year period for each site. It contains hourly measured global-horizontal and modeled direct solar radiation and meteorological data for specific calendar months selected as the most representative, or typical, for that station and month (i.e., a composite year, possibly with each month of data from a different calendar year). The data set was created by Sandia National Laboratories, Albuquerque, for DOE.

ETMY: A subset of the ERSATZ data base (208 of 222 sites), covering a one-year period for each site. EG&G

produced the data base and added modeled direct solar radiation data.

SOLDAY

Daily solar radiation and meteorological data for 26 sites across the United States, rehabilitated and reformatted. (NCDC Tape Deck 9739)

Historical Sunshine Data

Monthly and annual percentages of possible sunshine hours for 240 sites from 1891 to 1984. (NCDC Tape Deck 9788)

Input Data for Solar Systems

Heating and cooling degree days extracted from *Climatology of the United States* No. 81 (1941-1970) and monthly mean values of global-horizontal solar radiation from the SOLMET (1952-1975) data base. Data are monthly and annual averages for 248 sites, based on the entire period of record from 1952 to 1975. (NCDC Tape Deck 9744)

Weather Year for Energy Calculations (WYEC)

A one-year data subset (46 sites) from the SOLMET/ERSATZ data base, selected so that the mean values of the temperature and solar radiation (global horizontal) parameters for each month of data are the same as the long-term means for those parameters. (American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 404-636-8400, Atlanta, GA. Note: This data base supersedes the Test Reference Year [TRY] data set.) (NCDC Tape Deck 9706)

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