SOLAR THERMAL ENERGY

PRACTICAL ACTION
Technology challenging poverty

technical brief

Introduction

Although most research into the use of solar energy in recent years has been on photovoltaic technology, where sunlight is converted directly into electricity, there are many applications of solar thermal energy such as heating, drying and water distillation.

Many solar thermal technologies have existed for centuries and are well understood. They have established manufacturing bases in many sun-rich countries. Unlike photovoltaic technologies manufacturing can be done on a small scale without using expensive equipment. More sophisticated solar thermal technologies do exist that generate electricity (often on a large scale) but these are not covered in this technical brief.

Solar technologies that rely entirely on energy absorb from the sun and have no moving components, are referred to as *passive solar* technologies where as *active solar* technologies may have some additional input such as a pump to drive the system.

The nature and availability of solar radiation

Solar irradiation, or insolation is the "rate of delivery of direct solar radiation per unit of horizontal surface", measured in W/m^2. (Merriam-webster.com)

The earth revolves around the sun with its axis tilted at an angle of 23.5 degrees. It is this tilt that gives rise to the seasons. The strength of sun is dependent upon the angle at which it strikes the earth's surface, and so, as this angle changes during the year, so the solar insolation changes. Thus, in northern countries, in the depths of winter, where the sun is low in the sky to the south, the radiation strikes the earth's surface obliquely and solar energy is low.

The two phenomena described above provide an explanation for the variations of solar irradiation with season and lattitude.

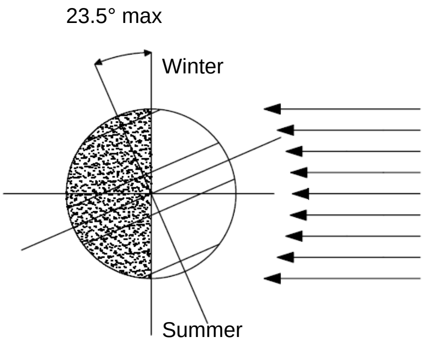

Figure 1: The angle of the earth to the sun changes throughout the year.
Illustration: Practical Action / Neil Noble

The total solar irradiation received in a day can vary from 0.5 kWh/m^2/day in the UK winter to 5 kWh/m^2 in the UK summer and can be as high as 7 kWh/m^2/day in desert regions of the world, such as regions of Nigeria (Solar Water Heating in Nigeria, 2006) and the Sahara in Algeria. (Survey of Energy Resources, 2010) Many tropical regions do not have large seasonal variations and receive an average 6 kWh/m^2/day throughout the year.

The diagram below shows the approximate percentages of direct and diffuse solar insolation that reaches the surface of the earth. As the direct insolation forms a larger proportion of the total received, it follows that varying factors such as the weather, i.e. cloud cover, and the time of day will greatly affect the amount of solar insolation reaching the surface of the earth (Powerfromthesun.net). It is interesting to note that whilst both direct and diffuse radiation is useful, diffuse radiation cannot be concentrated.

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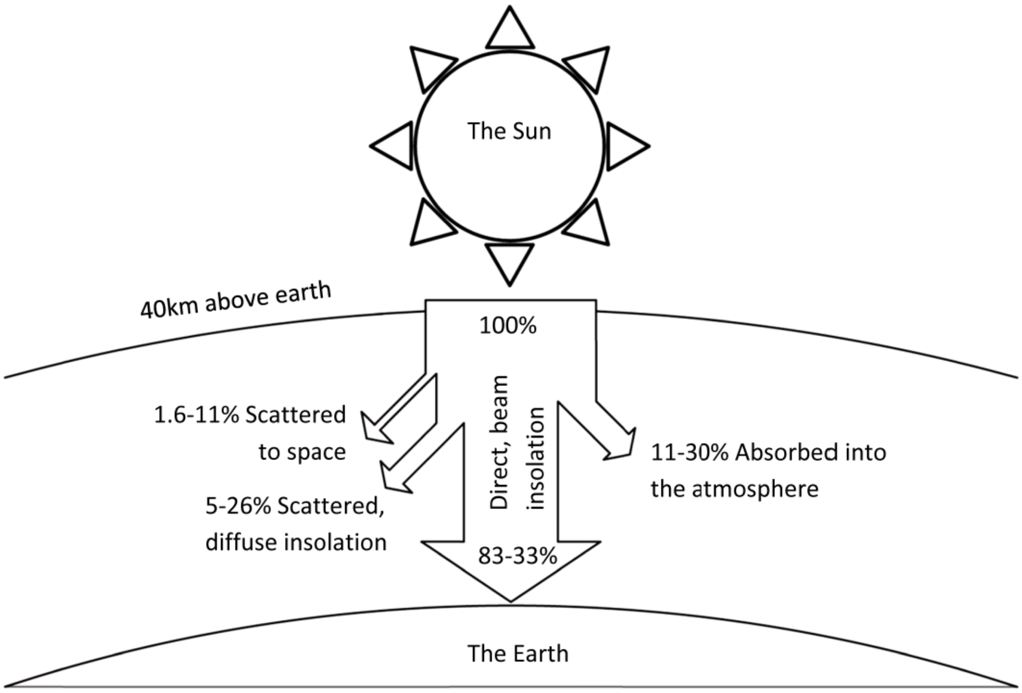
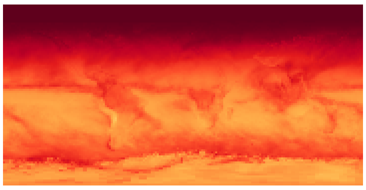


Figure 2: Dispersion of solar irradiance through the atmosphere. Illustration: Neil Noble / Practical Action (powerfromthesun.net).

Although potentially obvious, it is also useful to note that the majority of the solar water heating will occur during daylight hours. This is not necessarily when it is demanded, thus solar hot water storage tanks are normally required.

Daily, seasonal and geographical variations in solar insolation are an important aspect of solar energy because of the influence on system design and solar energy economics. A useful document which summarises the extent of the application of solar energy in 43 countries around the world is the 2010 Survey of Energy Resources by the World Energy Council. The document also notes the levels of solar radiation that can generally be expected in the countries listed which may be useful as a quick reference.

Alongside journals and books, another useful source detailing solar insolation levels around the world is a tool which has been developed by NASA and is free for public use. Below are images produced by this tool which show the global variation in solar insolation.



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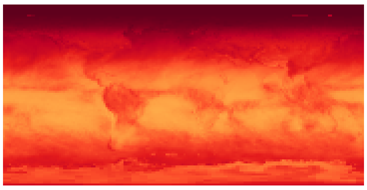

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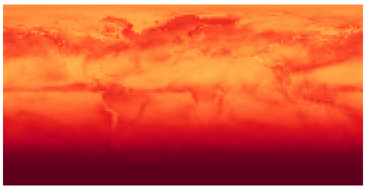

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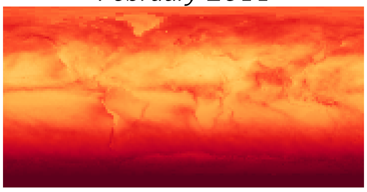

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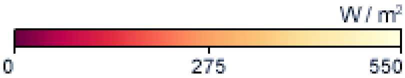

Figure 3: Examples of average monthly global variation of solar insolation in a year (NASA Earth Observations Website)

The analysis tool enables users to quantitatively investigate the variations in solar insolation in a particular region throughout the year. Three snapshots of either a daily average, average across eight days or monthly average, can be compared at once and presented in several different ways; either a probe, which gives the insolation at a particular point on the globe, a transect through a region (see Figure 4) or an average across a defined region. All three methods can be specified by the user.

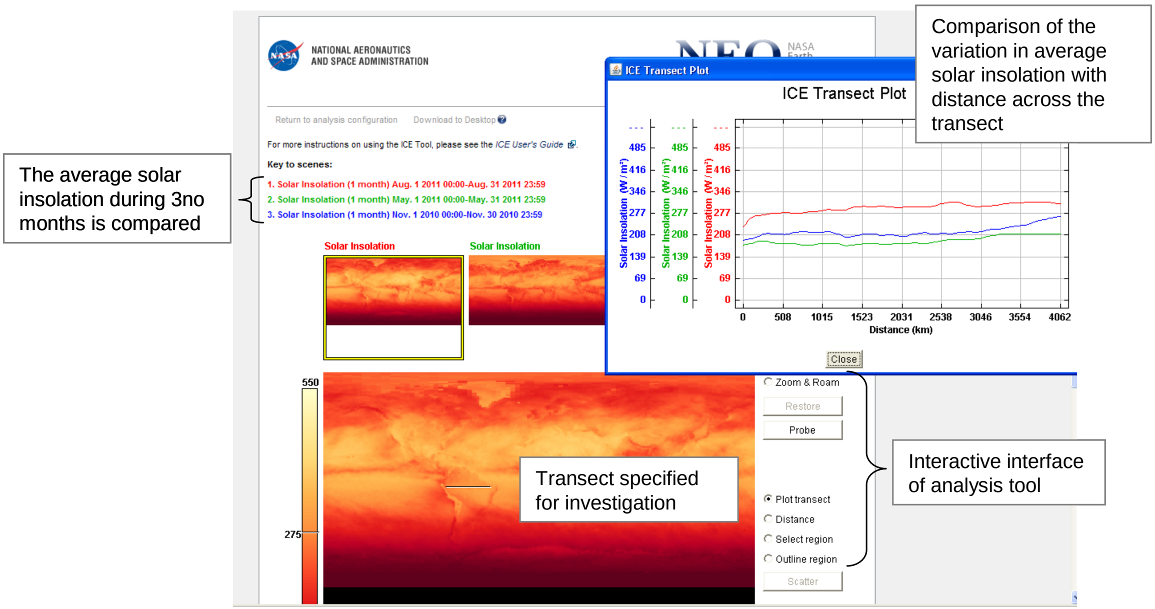

Figure 4: Screenshot of NASA Earth Observations Solar Insolation Analysis Tool

Each set of data can also be translated into the Google Earth software. This can be used to gain an overall impression of global solar insolation variation at a particular time.

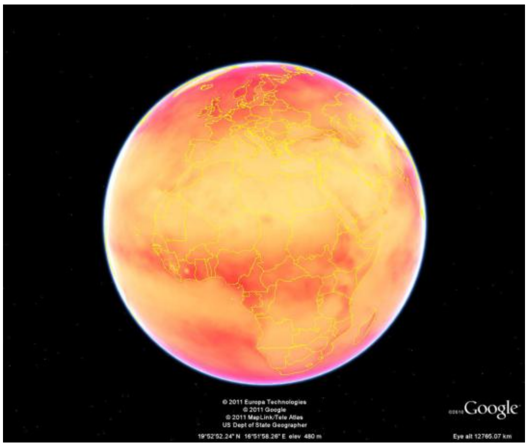

Figure 5: Data from NASA Earth Observations viewed in Google Earth

Solar thermal energy applications

Solar energy reaches the earth's surface as short wave radiation, absorbed by the earth and objects on the earth that heat up and re-radiated as long-wave radiation. Obtaining useful power from solar energy is based on the principle of capturing the short wave radiation and preventing it from radiating away into the atmosphere. For storage of this trapped heat, a liquid or solid with a high thermal mass is used. In a water heating system this will be the fluid that runs through the collector, whereas in a building the walls will act as the thermal mass. Pools or lakes are sometimes used for seasonal storage of heat.

Glass will allow short wave radiation to pass through it but prevents long wave radiation heat escaping.

If this energy is being used to heat water with a collector panel, then the tilt and orientation of the panel is critical to the level of energy captured and hence the temperature of the water. The collector surface should be orientated towards the sun as much as is possible. Most solar water-heating collectors are fixed permanently to roofs of buildings and cannot be adjusted. More sophisticated systems for power generation use tracking devices to follow the sun through the sky during the day.

There are many methods available for aiding system design and for predicting the performance of a system. The variability of the solar resource is such that any accurate prediction requires complex analytical techniques. Simpler techniques are available for an approximate analysis.

Water heating

The most common use for solar thermal technology is for domestic water heating. Hundreds of thousands of domestic hot water systems are in use throughout the world, especially in areas such as the Mediterranean and Australia where there is high solar insolation (the total energy per unit area received from the sun). Presently, domestic water heaters are usually only found amongst wealthier sections of the community in developing countries.

Figure 6: Solar water heaters in Nepal. Photo: Practical Action.

Low temperature (below 100ºC) water heating is required in most countries of the world for both domestic and commercial use. There are a wide variety of solar water heaters available. The simplest is a piece of black plastic pipe, filled with water, and laid in the sun for the water to heat up. Simple solar water heaters usually comprise a series of pipes that are painted black, sitting inside an insulated box fronted with a glass panel, this is known as a solar collector. The fluid to be heated passes through the collector and into a tank for storage. The fluid can be cycled through the tank several times to raise the heat of the fluid to the required temperature. There are two common simple configurations for such a system and they are outlined below.

- The *thermosyphon* system makes use of the natural tendency of hot water to rise above cold water. The tank in such a system is always placed above the top of the collector and as water is heated in the collector it rises and is replaced by cold water from the bottom of the tank. This cycle will continue until the temperature of the water in the tank is equal to that of the panel. Where there is a main water supply fresh cold water is fed into the system from the mains as hot water is drawn off for use. A one-way valve is usually fitted in the system to prevent the reverse occurring at night when the temperature drops.

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Open loop systems allow water to run through the solar panels and be stored in the storage tank to be used.

Closed loop systems are where the water that circulates through the solar panel is separate from the water used. The system uses a heat exchanger. This means that anti freeze can be added to the water running through the panels which allows them to be used in cold climates.

Atmospheric systems are used where there is no mains water delivery to the storage tank so as water is taken from the hot water tank it is replaced from an additional cold water tank that is located above it. A break pressure valves allows water to feed the hot water tank when required. Atmospheric systems can be open loop or closed loop.
Batch solar water heating systems are used as a simple approach to obtaining hot water. The system is filled with water and left to heat up. Once the water is heated up it can be used as required but system has to be refilled manually.

> Simple Solar Water Heater for Developing Countries
> A. Jagadeesh, Homepower Issue 76 http://www.homepower.com/

More than 90% of systems worldwide are based on the thermosyphon principle.

- Pumped solar water heaters use a pumping device to drive the water through the collector. The advantage of this system is that the storage tank can be sited below the collector. The disadvantage of course is that electricity is required to drive the pump. Often the fluid circulating in the collector will be treated with an anti-corrosive and /or anti-freeze chemical. In this case, a heat exchanger is required to transfer the heat to the consumers hot water supply.

Integrated systems combine the function of tank and collector to reduce cost and size.

Water heating systems can be made relatively simply while more sophisticated systems are available at a higher price. Evacuated tube collectors have the heat absorbing element placed within an evacuated glass sheath to minimise heat losses. System complexity also varies depending on use.

For commercial applications, banks of collectors are used to provide larger quantities of hot water as required. Many such systems are in use at hospitals in developing countries.

A solar pond is an approach that uses large bodies of water to collect and store solar thermal energy with relatively little equipment. The pond uses the principle that slat water is heavier than fresh water so a layer of salt water at the bottom of the pond traps the heat energy and the temperature can rise above 90°C.

Solar ponds can be used to provide heating to houses but can also be used for other applications. For example, using a low temperature turbine the solar pond can be used to generate electricity or it can be used to provide power to a water distillation unit as developed by The University of Texas.

Bhuj, Gujarat has the largest operating solar pond in India covering an area of 6000 m^2 which is used to supply process heat to the Kutch dairy.

The solar pond was developed by the Gujarat Energy Development Agency (GEDA), the Tata Energy Research Institute (TERI) and the Gujarat Dairy Development Corporation (GDDC).

http://www.teriin.org/tech_solarponds.php

Solar drying

Controlled drying is required for various crops and products, such as grain, coffee, tobacco, fruits vegetables and fish. Their quality can be enhanced if the drying is properly carried out. Solar thermal technology can be used to assist with the drying of such products. The main principle of operation is to raise the heat of the product, which is usually held within a compartment or box, while at the same time passing air through the compartment to remove moisture. The flow of air is often promoted using the 'stack' effect which takes advantage of the fact that hot air rises and can therefore be drawn upwards through a chimney, while drawing in cooler air from below. Alternatively a fan can be used. The size and shape of the compartment varies depending on the product and the scale of the drying system. Large systems can use large barns while smaller systems may have a few trays in a small wooden housing.

Figure 7: Coconut drying in Bangladesh.
Photo: Practical Action / Neil Cooper.

Solar crop drying technologies can help reduce environmental degradation caused by the use of fuel wood or fossil fuels for crop drying and can also help to reduce the costs associated with these fuels and hence the cost of the product. Helping to improve and protect crops also has beneficial effects on health and nutrition.

Solar wood kiln have been developed to season timber. The Solar kiln is constructed using a wooden frame with a glass roof placed over the top. The principles are similar to that of a green house design. The simplest have been modified greenhouses designed to take large pieces of wood for drying. Air is passed through the kiln to remove the moisture from the air and the cycle continues.

Solar cooking

Solar cookers fall into two main categories – solar ovens and direct solar concentrators. The basic design for a solar oven is that of a box with a glass cover. The box is lined with insulation and a reflective surface is applied to concentrate the heat onto the pots. The other approach is to reflect the suns rays onto a put, often with a parabolic dish. The pots can be painted black to help with heat absorption.

On a domestic scale the cookers have limitations in terms of only being effective during hours of strong sunlight. Another cooking stove is usually required for the periods when there is cloud or during the morning and evening hours. Cooking time is often a lot slower than conventional stoves and cooking practice has to be adapted to suit. However, the main advantage to solar cookers is that wood does not need to be purchased or collected, which is often a very time consuming activity for women.

Many variations of solar cooker have been developed from the very basic reflective cardboard sheet box to the very sophisticated large-scale institutional and commercial solar cookers now being used in India.

Desalination /distillation

Basic solar stills can be used to purify water in remote regions where contaminated water is present. They can be used to remove impurities such as fluoride and salts to produce drinking water.

The basic still is made of a glass or transparent plastic cover and a shallow tray of water which has a black backing to trap energy. When the sun heats the water up within the still water evaporates which then condenses on the underside of the covering glass. The glass is at an angle so the water drains off and is captured in a trough separate to the contaminated water.

Solar distillation can be combined with other useful functions so that a solar still may also be used for rainwater harvesting if modified slightly.

Solar pasteurisation

In pasteurization, water is heated to 149°F (65°C) for about six minutes, killing all the germs, viruses, and parasites that cause disease in humans, including cholera and hepatitis A and B. This is similar to what is done with milk and other beverages. It is not necessary to boil the water as many people believe. Pasteurization is not the only way to decontaminate drinking water, but it is particularly easy to scale down so that the initial cost is low.

The Solar Puddle - A New Water Pasteurization Technique Boiling Point No. 36 - November 1995, GTZ, Practical Action.

Refrigeration / cooling

Preservation of crops and food can be improved with relatively simple evaporative cooling techniques. This approach keep produce fresh by using the evaporation of water to reduce the temperature minimise the impact of the suns energy. Evaporative cooling works best in dry climates and the greater the amount of humidity in the air the less effective it is at reducing the temperature. A similar approach has been use to keep building cool by placing a ceramic pot containing waster in window and allowing the air to pass over the pot as it enters the building. This results in a cooler wetter environment in the room.

Solar thermal energy in architecture

There are two basic requirements within buildings – heating and cooling. Many technological advances have been made in design of 'solar buildings' for solar heating in developed countries but the technology is often expensive and out of reach for rural communities in developing countries.

Space cooling

The majority of the world's developing countries, however, lie within the tropics and do not need space heating but there is a demand for space cooling. There are many traditional, simple, elegant techniques for cooling their dwellings, often using effects promoted by passive solar phenomenon.

There are many methods for minimising heat gain. These include siting a building in shade or near water, using vegetation or landscaping to direct wind into the building, good town planning to optimise the prevailing wind and available shade. Buildings can be designed for a given climate - domed roofs and thermally massive structures in hot arid climates, shuttered and shaded windows to prevent heat gain, open structure bamboo housing in warm, humid areas. In some countries dwellings are constructed underground and take advantage of the relatively low and stable temperature of the surrounding ground. There are as many options as there are people.

Space heating

In colder areas of the world (including high altitude areas within the tropics) space heating is often required during the winter months. Vast quantities of energy can be used to achieve this. If buildings are carefully designed to take full advantage of the solar insolation which they receive then much of the heating requirement can be met by solar gain alone. By incorporating certain simple design principles a new dwelling can be made to be fuel efficient and comfortable for habitation. The bulk of these technologies are architecture based and passive in nature. The use of building materials with a high thermal mass (which stores heat), good insulation and large glazed areas can increase a buildings capacity to capture and store heat from the sun. Many technologies exist to assist with diurnal heating needs but seasonal storage is more difficult and costly.

For passive solar design to be effective certain guidelines should be followed:

- a building should have large areas of glazing facing the sun to maximise solar gain
- features should be included to regulate heat intake to prevent the building from overheating
- a building should be of sufficient mass to allow heat storage for the required period
- contain features which promote the even distribution of heat throughout the building

One example of a simple passive space heating technology is the Trombe wall. A massive black painted wall has a double glazed skin to prevent captured heat from escaping. The wall is vented to allow the warm air to enter the room at high level and cool air to enter the cavity between the wall and the glazing. Heat stored during the wall during the day is radiated into the room during the night. This type of technology is useful in areas where the nights are cold but the days are warm and sunny.

Greenhouses

It is possible to expand the diversity of crops grown in mountain areas and therefore enhance the nutritional balance of family diets by the use of simple greenhouse structures. However, the low-cost materials such as polythene sheets and wooden pole frames are vulnerable to damage in the harsh climate of mountainous regions.

Seawater Greenhouse

A solar energy application in which evaporative cooling and desalination are combined to produce an enhanced environment for crops to grow in hot arid regions and provide clean water.

Seawater is fed onto porous cardboard evaporators and humidified air is drawn into the greenhouse. This provides a cooling effect that reduces the temperature within the greenhouse. At the other end of the greenhouse a plastic condenser captures the clean water from the air. The condenser uses cold seawater as a coolant.

The greenhouse is made of a light steel structure with a polythene covering. The polythene films are treated to incorporate ultraviolet-reflecting and infrared-absorbing properties. The cardboard evaporators become strengthened by the crystallise calcium carbonate from the sea water.

http://www.seawatergreenhouse.com/

Less common applications

Solar-thermodyamic water pumping

Many solar water pumping systems are based on photovoltaic technology combined with a battery storage system and an electric pump. Solar thermodynamic systems use the heat from the sun to power a pump.

The system can be divided into the following components

- The solar collector which converts radiation to heat
- The heat engine which uses a thermodynamic cycle to convert heat into mechanical energy
- The pump
- The water storage and distribution system

To convert the thermal energy to mechanical pumping a heat engine is used which can be based on a Ranking cycle or a Stirling cycle. These engines operate through the use of external heat sources including solar energy but any heat source can be used. In addition to driving a water pump these heat engines can also be used in other applications and can generate electricity when combined with a generator.

A solar washing machine

An industrial solar heated washing machine was developed by FAKT, Enegética (a Bolvian NGO), and PROPER (A joint project between GTZ (now GIZ) & The Bolivian Ministry of Enegry). The water is heated by solar energy

The first washing machine was installed in the hospital in Tipuipaya, Bolivia in 1996 to replace hand washing. The electricity bill for the hospital accounted for 1/3rd of the hospital's budget so a conventional electric washing machine would have been too costly.

This doubled the amount of washing but there were difficulties with removing blood stains which meant that some pre washing was required.

Other uses

There are many other uses for solar thermal technology such as solar thermal power stations that generate electricity. These are complex technologies that require large capital investment and are not covered in this technical brief. Many of the active solar technologies rely on sophisticated, exotic modern materials for their manufacture. This presents problems in developing countries where such materials have to be imported. Some countries do have a manufacturing base for solar thermal products but it is often small and by no means widespread.

The market for solar products in developing countries, such as solar water heaters, is small but growing.

References and resources

Articles and fact sheets

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Solar Drying Technical Brief Practical Action
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Solar Distillation Technical Brief Practical Action
Refrigeration in Developing Countries Technical Brief Practical Action
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