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Barriers to Technology Diffusion: The Case of Solar Thermal Technologies

Cédric Philibert, IEA

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FOREWORD

This document was prepared by the OECD and IEA Secretariats in September-October 2006 in response to the Annex I Expert Group on the United Nations Framework Convention on Climate Change (UNFCCC). The Annex I Expert Group oversees development of analytical papers for the purpose of providing useful and timely input to the climate change negotiations. These papers may also be useful to national policy-makers and other decision-makers. In a collaborative effort, authors work with the Annex I Expert Group to develop these papers. However, the papers do not necessarily represent the views of the OECD or the IEA, nor are they intended to prejudge the views of countries participating in the Annex I Expert Group. Rather, they are Secretariat information papers intended to inform Member countries, as well as the UNFCCC audience.

The Annex I Parties or countries referred to in this document are those listed in Annex I of the UNFCCC (as amended at the 3rd Conference of the Parties in December 1997): Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, the European Community, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great Britain and Northern Ireland, and United States of America. Korea and Mexico, as OECD member countries, also participate in the Annex I Expert Group. Where this document refers to "countries" or "governments", it is also intended to include "regional economic organisations", if appropriate.

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Questions and comments should be sent to:

Cédric Philibert
International Energy Agency
9, rue de la Fédération
75739 Paris Cedex 15
Email: cedric.philibert@iea.org
Fax: +33 (0)1 4057 6739

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Executive Summary

Despite its considerable potential in household, domestic and industry sectors, the possible contribution of solar heat is often neglected in many academic and institutional energy projections and scenarios. This is best explained by the frequent failure to distinguish heat and work as two different forms of energy transfers. As a result, policy makers in many countries or States have tended to pay lesser attention to solar thermal technologies than to other renewable energy technologies.

Solar thermal technologies offer a great potential for providing a carbon-free response to mankind's energy demand – about half of it being of heat form. After decades of development they have now reached a degree of technical maturity that makes them reliable. Passive solar technologies are said cost-effective in most places for new constructions, but their development is limited by the slow turn-over of buildings in developed countries. Sanitary water heating is cost-effective in some places and getting close to cost-effectiveness in many others, but other technologies, including active solar heating and cooling, see their economic viability more dependent on various local conditions, from labour costs to resource availability to the repartition of the demand for heat over the year.

Numerous barriers still impede the dissemination of these technologies. Most technical barriers have now been fixed, although technical limitations persist; unfortunately, past failures have left some distrust in the public and policy makers' opinion in many countries. Other barriers include high investment costs, failures to account for the public energy security and environmental benefits, insufficient training of professional installers, "split incentives" and other institutional barriers, legal barriers such as permitting, and lack of awareness of the potential by customers as well as policy makers.

The uneven level of solar thermal markets in countries with similar climate and energy conditions highlights the importance of public policies to overcome the barriers to their use.

Policies to overcome these barriers may include support to research, development and demonstration programmes and support to market deployment through public outreach and professional training, certification of components guarantees of performances of systems and the establishment of solar energy service contracts. Various schemes may help overcome the financial barriers, from direct subsidies and fiscal incentives to inclusion of solar thermal technologies in green certificates systems (or renewable energy portfolio obligations), white certificate systems (or energy efficiency obligations), carbon trading and project-based mechanisms. Co-operative private and/or governmental procurement could further reduce costs and accelerate dissemination. Reducing import tariffs would also help internationally disseminating solar thermal technology hardware.

Existing regulations may act as undesirable barriers, and governments must act to remove them as possible, streamlining and simplifying the necessary permitting procedures. Governments and local authorities may want to go much further by establishing new obligations to satisfy part of the heat demand of new buildings with solar technologies, as one IEA country did a few months ago.

1. Introduction

Since 2003 the Annex I Expert Group (AIXG) on the United Nations Framework Convention on Climate Change has investigated issues relating to technology development and diffusion, with an emphasis on international collaboration. Two papers, followed by five case studies and a synthesis paper, were published between 2003 and 2005 (see Justus and Philibert, 2005). To build on this work, the AIXG, at its meeting in March 2006, requested the secretariat to prepare case studies on the barriers to the diffusion of climate-friendly technologies, starting with a report on solar thermal technologies.

This paper responds to that request. It analyzes the barriers to the diffusion of solar thermal technologies (excluding electric power production, see Philibert, 2004a). The aim is to identify barriers of various kinds, lessons learned from successes and failures, and suggestions for consideration by policy makers, in both industrialised and developing countries, who wish to expand the use of solar thermal and other climate-friendly technologies. While international technology collaboration has been the focus of earlier AIXG papers on technology, it may not be in this new analytical effort, although it could part of it.

In many cases, solar thermal technologies seem to have been somewhat forgotten by policy makers – the policies to support them seem less developed than for other renewable energy technologies. Solar thermal technologies are often viewed as ‘low tech’. Yet they currently provide a greater contribution to global energy demand than solar electricity – photovoltaic (PV) and concentrating solar power (CSP) altogether – and have the potential to contribute much more toward meeting global energy demand

Yet solar technologies have faced significant challenges. They have been thought to have a brilliant future – but most of the hopes have not been realised so far. As Bezdek and Wendling (2002) suggest, projections made 20 years ago or so in the USA may have overestimated the current contribution of solar and wind by a factor of 40 on average: *“The future contribution of solar energy and renewables has been consistently misforecast for the past 50 years; for example, the 1952 Paley Commission report predicted 10 million solar homes in the US by 1975; the 1977 U.S. National Energy Plan predicted 2.5 million solar homes by 1985”*. Between these projections and the reality there must have been numerous barriers to the diffusion of these technologies, starting with unexpectedly high costs and, at the same time, low oil and gas prices. At the time of a renewed interest in (and seemingly a new start of) solar technologies, understanding these barriers and identifying possible ways to overcome them seems more important than ever.

This paper considers the solar resource, the demand for heat, the technologies and the markets. It also analyses the barriers – technical, economical and other – to the diffusion most frequently encountered by market players, and describes some policies that have been designed to address these barriers, looking at successes and failures. The conclusion provides suggestions policy makers may wish to consider if they want to expand the use of solar thermal technologies

2. The Solar Resource and the Demand for Heat

The sun’s radiative energy that keeps our planet warm by far exceeds the current primary energy supply used by mankind for its comfort, leisure and economic activities. It also vastly exceeds other energy sources at ground level such as geothermic or tidal energy, nuclear power and fossil fuel burning. Sunrays also drive hydraulics, wind and wave power and biomass growth.

Mankind’s total primary energy supply (TPES) was 433 Ej in 2002, including non-commercial biomass, equivalent to a continuous power consumption of 13.75 TW. This compares to the solar radiation intercepted by the Earth of 173,000 TW, of which 120,000 TW strike the Earth’s surface (the difference being reflected by the atmosphere directly to the outer space). Solar energy is thus the primary energy source on our planet’s surface – and exceeds 8,700 times our current primary energy supply. In other words, the Earth receives from the sun each hour as much energy as mankind consumes in a year. The IEA projects a TPES of about 688 Ej in 2030, equivalent to 21.8 TW of power (IEA 2004). Solar energy would still be 5,500 times greater.

The drawbacks are well-known: the solar radiation reaching the earth is very dilute (only about 1 kW_{th} per square meter), intermittent and unequally distributed over the surface of the earth (mostly between 30° north and 30° south latitude). Intermittence means that the resource is, of course, available only during day-time, and weather-dependent. Perhaps more importantly, the resource is weaker when the heating demand is greater – in winter (although the demand for cooling is conversely greater when the resource is stronger). They are, in some sense, the primary barriers that have to be addressed for using solar thermal energy.

Solar "thermal" energy designates all technologies that collect solar rays and transform their energy into usable heat, either for directly satisfying heating needs or for producing electricity and fuels. This paper focuses on low and mid-temperature solar resources for use in water and space heating and cooling, and agriculture and industry processes; it does not address the technologies that aim at producing solar electricity or fuels.

Uses of heat represent only a subset of all final energy use – other forms being work and light. Precise information on the share of heat in useful energy uses is hard to find. However, the World Nuclear Association concludes: *"The main role of solar energy in the future will be that of direct heating. Much of our energy need is for heat below 60°C - e.g., in hot water systems. A lot more, particularly in industry, is for heat in the range 60 - 110°C. Together these may account for a significant proportion of primary energy use in industrialised nations. The first need can readily be supplied by solar power much of the time in some places, and the second application commercially is probably not far off."* (World Nuclear Association, 2005).

But how much are "much" and "significant"? A very rough estimate would suggest heat demand is probably close to half the total useful energy demand – perhaps slightly less (see box 1). This by no means implies that solar thermal, alone or in combination with other renewable heat sources (geothermal, biomass), could or should provide the bulk of such an important share of primary energy – plus some work through solar cooling. Still, it shows the value of carefully distinguishing heat and work in analysing energy demand, to give solar heating its fair potential share.

Box 1: Heat and work: about fifty-fifty?

IEA statistics detail the use of various energy products by sectors and by countries, and give aggregate numbers for primary energy sources. They include the heat produced and sold as heat to third parties, as well as the final consumption of this commercial heat by the buyers. This, however, is only part of the energy finally used as heat, as other commercial fuels, including electricity, are often used to produce heat. The real repartition of final energy forms between work and heat remains elusive.

What should be accounted for? Although some of it could be used, e.g. in cogeneration, to cover part of useful heat demand, the heat in internal combustion engines or power plants is readily transformed into useful work or electricity. It is thus not accounted for in final heat. Low and high temperature heat in housing, retail, services, industry and agriculture, including space heating and process heat must be accounted for (but in case of refineries another choice would be possible). Cooling requires pumping heat out of a place, and this is work (but low temperature solar thermal energy can provide for some of this work); heat pumps work the same in the other way but respond to a demand for heat.

Heat demand in the transport sector is usually considered zero, as most heat load is provided as a by-product of fuel consumption for work. However, at a minimum, heating needs in electrical vehicles, including rail-guided transport, should be accounted for, as well as the energy of plug-in or fossil-fuelled pre-heaters when it satisfies comfort. A comprehensive assessment should in fact also take into account the “free heat” from the engine… as well as other free heat sources in buildings, such as incoming solar rays and wasted heat from light bulbs, ovens and appliances.

Global estimates have been 81% heat and 19% work in 1952 (Gardel, 1979), while in the US at about the same time work already constituted 55% against comfort heat 34% and process heat 11% (Putnam, 1953). Since then, however, transport fuels and electricity, notably for lighting and specific usages (information processing, which could be considered work), have grown more rapidly than other usages. The share of heat thus slowly decreases over time. Climate change itself speeds that evolution, in reducing comfort heat demand and increasing cooling work loads, as suggest Ure and Colyer (2006): *“Space-heating loads are reducing. The most obvious driver for this reduction is the direct effect of climate change. The average UK winter temperature has risen from 5.8°C in 1970 to 7.2°C in 2000.”*

In IEA member countries, comfort heat (space heating plus domestic hot water) is about 75% of the energy consumed in buildings, itself about 40% of all final energy demand. This does not include all useful heat, though: heat in washing machines, dish-washing machines, drying machines, ovens, cooking devices, hair dryers, irons, boilers and others. Most available estimates consider that 30 to 40% of industrial energy in industrialised countries is consumed as heat; industry consumption (excluding electricity production) is about a fourth of the final demand.

Adding these numbers suggests a share of heat of about 40 % or more – taking into account “free heat” sources. A few energy administrations have provided recent information, revealing that heat represent 48% of final energy demand in France, 58% in Germany and Switzerland.

Information is even scarcer on final heat demand in developing countries. Many countries have little space heating needs, and sanitary hot water is a luxury for most people in least-developed countries. Still, heat demand for cooking represents the bulk of their small energy consumption. Emerging economies, where transport and electricity are more developed, may have quite different shares of heat in their final energy demand depending on climate.

In sum, the share of heat in the global demand is probably greater than 40%, possibly higher than 50%.

3. The Technologies and the Markets

At present, solar heating and water heating provides by far the largest solar contribution to energy needs. The main technologies belong to either “passive” and “active” solar energy forms. Passive solar energy relates to the design of buildings collecting and transforming solar energy used for passive heating, day lighting and natural ventilation. Active solar energy relates to the use of solar collectors for water and/or space heating purposes, active solar cooling, heat pumps, desalinisation and industrial heat.

3.1 Passive solar architecture

Passive solar energy does not show up in energy statistics as collecting data would be quite expensive, requiring building-by-building examination. Passive solar energy is usually considered from the demand side as part of energy savings potential rather than from the supply side. Through a combination of a high-performance thermal envelope, efficient systems and devices, and full exploitation of the opportunities for passive solar energy, 50 to 75% of the energy needs of new buildings as constructed under normal practice can be either eliminated or satisfied through passive solar means. In existing buildings improvements can be made but reductions in energy consumption will be less important.

From an art to a science

Passive solar heating can involve extensive sun-facing glazing, double-façade wall construction, air-flow windows, thermally massive walls behind glazing, or preheating of ventilation air through buried pipes. An excellent insulation and heat exchangers for indoor air are also essential part of an effective solar architecture. Wall- or roof-mounted solar air collectors can be elements of solar architecture although they could be considered “active” solar technologies.

Lighting and ventilation can be directly supplied through solar energy – interior light through a variety of simple devices that concentrate and direct sunlight deep into a building, and ventilation through the temperature and hence pressure differences that are created between different parts of a building when the sun shines. The building façade can be used to generate and channel airflows that remove heat that otherwise add to the cooling load, or which can be used to preheat ventilation air when heating is required.

Efficient passive solar architecture was usually considered an art as much as a science. Indeed, there is no one-fits-all recipe. Quite to the contrary, each new building requires a close adaptation to its natural environment and climate, and the needs of its inhabitants. Buildings made during the era of cheap oil and standardised building materials and concepts are more often the examples not to follow. Very often traditional materials and knowledge can be a great source of inspiration for designers and architects. This may be especially true in hot climate where a reasonable level of comfort can be provided with a variety of energy-efficient devices high-inertia materials to avoid using air-conditioning systems. However, new tools have been developed for architects and engineers, such as the “Integrated Design Process”, which can greatly help them in achieving excellence in building design.

Innovative materials

This does not preclude, however, the use of modern computer software or up-to-date materials, with emerging new standardised materials for walls, doors and windows. For example, spectrally selective windows can maximise sunlight to replace lighting while minimising increased cooling requirements from solar radiation. Electro-chromatic windows can be reversibly switched from a clear to a tinted state with a control. They can minimise both winter heating requirement and summer cooling needs. Simulations of energy use in office buildings with the climate of New York State indicate that such windows can achieve a savings in combined lighting and cooling electricity use of up to 60%, depending on the building characteristics and window area. Another technology under development is thermo chromatic glazing, which automatically permits penetration of solar radiation only when heating is desired, eliminating the need for sensors.

Beyond architecture

Passive solar architecture extends to the buildings' neighbourhood, as pergolas, vegetation, fountains, spraying devices may offer either winter protection against cold winds or summer protection against sunrays or both. One step further is urbanism, as the spatial organisation of buildings strongly influences cooling and heating loads. Lessons can be taken from many old cities in various climates. Modern urbanisation, with its large energy consumption, creates heat island effects that reduce winter heat loads but increase summer cooling work loads.

Markets and contribution

There is no single market for passive solar energy as it extends from architects' work to markets for some components, often considered components for energy efficiency improvements as well. Similarly, the output of passive solar energy is not accounted for in supply statistics. Estimates for a project are abundant but there are no reliable global estimates. According to the EU Commission (1997), an amount of energy equivalent to about 40% of the energy actually consumed in the building sector is in fact gained from solar energy through windows, but this passive energy supply is not accounted for in statistics.

3.2 Active solar technologies

Active solar technologies use solar collectors to heat a fluid, usually water. The main collector technologies considered include unglazed, glazed flat plate and evacuated tubes collectors. A flat plate collector runs plastic or copper tubing through an insulated, weather-proofed box. Evacuated tube collectors are made up of rows of parallel, transparent glass tubes. The main advantage of vacuum tubes is the lower heat loss due to the vacuum. Many of the vacuum tube designs have a flat absorber. Others, called circular absorbers, do not; the additional advantage of circular absorbers is that the sun's rays remain perpendicular to the tubes for most of the day, increasing daily solar yields.

The technology may be considered mature but continues to improve. Aluminium, being cheaper and lighter than copper, is being increasingly used in manufacturing absorbers. Laser welding technology makes it possible to have a perfectly smooth absorber surface and obtain a homogenous colour. Heat storage is another important area for improvement. Unglazed collectors made of plastic are mostly used for heating the water in swimming-pools.

Sanitary hot water

Small scale, low temperature solar thermal systems can supply heat for domestic hot water. The main components – the collectors – can be installed in various kinds of systems almost always including some hot water tank.

The simplest type of domestic hot water system is the thermo siphon monobloc, easy to install and get in operations. Natural flow systems (thermo siphon with separate collector and storage areas) work without any need for pumps or control stations. Forced circulation systems are more complex, and can cover also space heating. Most systems use a back-up from biomass (pellets), fossil fuel or electricity in industrialised countries, but a majority of systems in developing countries, solar water heaters are often the sole source of hot water. In areas where freeze might be an issue, the collectors are usually protected using a separate pressurized water circuit with additives and heat exchangers. Another technique against freeze and overheating altogether is drain back systems, where the water is evacuated by gravitation from the collectors if it risks freezing or boiling.

Depending on location, sanitary hot water may represent significant share of electric or natural gas markets. For example, in South Africa water heating accounts for an average of 30-50% of household electricity bills. Appropriate solar water heating systems have the potential to save up to 70% on water heating electricity costs and up to 40% on total household electricity costs (DME, 2002).

Solar space heating

The same kind of solar collectors used for domestic hot water can be used for heating houses, offices, schools, hotels, warehouses and other types of buildings. Most systems are in fact “Combisystems” that provide space and water heating altogether. Air collectors represent 1% of the overall market. Unglazed metal collectors are increasing in market share for use in ventilation air heating for commercial and industrial buildings, notably in Canada.

The efficiency of solar collectors (heat delivered to where it is wanted divided by incident solar energy) depends on the design of the collector and on the system of which the collector is a part – in particular storage and back-up systems. Annually averaged collector efficiencies of 40-55% are feasible for domestic hot water, while annual averaged solar utilisation (which accounts for storage losses and heat that cannot be used) of 20-25% have been obtained in combisystems. Depending on the size of collectors and of storage tanks and of the building thermal envelope, 10-60% of the combined hot-water and heating demand can be met at central and northern European locations.

Solar collectors of all types have a nominal peak capacity of about 0.7 $kW_{th}.m^{-2}$. However, the estimated annual solar thermal energy production from the collector areas in operation depends on the solar radiation available, the outside temperature, the application and the solar thermal technology used. For example estimated annual yields for glazed flat-plate collectors are 1000 $kWh_{th}.m^{-2}$ in Israel, 700 to 1000 $kWh_{th}.m^{-2}$ in Australia and 525 $kWh_{th}.m^{-2}$ in Germany.

District heating systems, heat pumps

District heating and cooling systems can be made solar and combined with some form of thermal energy storage. By 2003, eight solar-assisted district heating systems had been constructed in Germany. Other such systems exist in Sweden, Denmark, The Netherlands, Austria and other countries. The largest of these, in Denmark, involves 1300 houses, a 70 000 m^3 gravel-pit for storage, and a 30% solar fraction.

Heat pumps use an energy input (almost always electricity) to transfer heat from a cold medium (the outside air or ground or seawater in the winter) to a warmer medium (the warm air or hot water used to distribute heat in a building). Heat pumps are said to use respectively geothermal energy or solar energy when they use the ground or the outside air as heat source. Heat pumps with evaporators exposed to direct solar radiation operate as both a direct solar collector and as an air source heat pump (“solar boosted” heat pumps).

During hot weather, the heat pump can operate in reverse (transferring heat from a hot to a cold medium), thereby providing cooling. The coefficient of performance (COP) of a heat pump is the ratio of heat supplied to energy used. The COP of a conventional system is 2-2.5. It increases to 3.5-7.0 for a radiant heating system. The ground can also serve as a low-temperature heat sink in summer, increasing the efficiency of air conditioning as well.

Solar cooling

Solar thermal energy can be directly used for cooling and dehumidification – substituting to work, not heat. Cooling technologies include single- and double-effect absorption chillers, adsorption chillers, and solid or liquid desiccant systems. There are about 100 solar air conditioning systems in Europe, with a total solar collector area of about 24,000 m^2 and a total capacity of about 9 MW chilling power. A prototype indirect-direct evaporative cooler has been recently developed in California. The coefficient of performance (cooling power divided by fan power, a direct measure of efficiency) ranges from about 12 to about 40. Simulations for a house in a variety of California climate zones indicate savings in annual cooling energy use of 92 to 95%. In humid climates the energy savings would be much less, however.

Markets and contribution

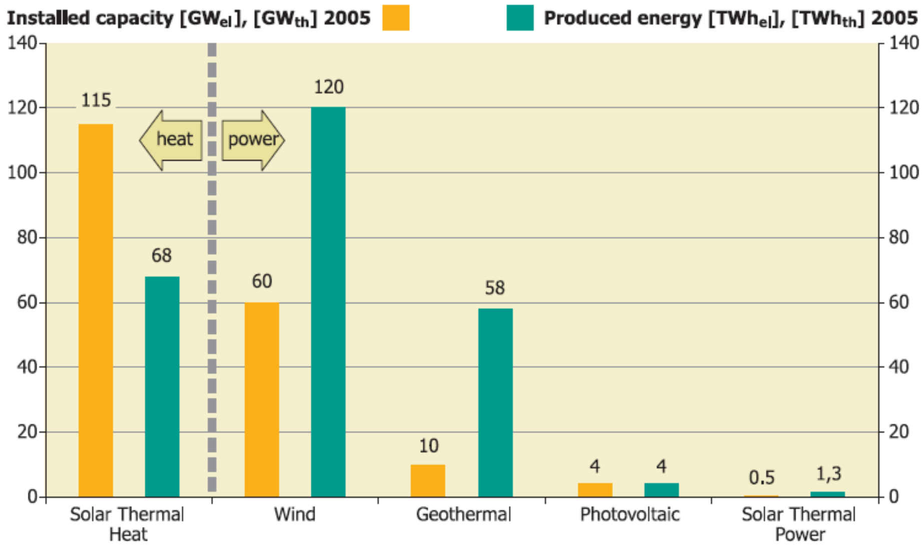
About 164 million m^2 of solar thermal collector area were in operation around the world at the end of 2004, and the annual newly installed area is 20 million m^2. The total installed capacity is thus estimated at 115 GW_{th}. China is the world lead market, with 38% of the global installed capacity, mostly (89%) evacuated tubular collectors. The USA ranks second with 17.4%, mostly (92%) plastic collectors for swimming pools, before Japan (4.7%), Turkey (4.4%), Germany, Israel and Australia. Evacuated tubes represent 41% of all installations, flat-plate collectors 35%, unglazed 23% and air collectors 1%. (Weiss et al, 2006)

The EU altogether accounts for 10.4%. Lead European markets are Germany, Greece and Austria. The highest collector surface area per inhabitant is Cyprus with 582 m^2, followed by Austria 297 m^2, far above the EU average of 33.7 m^2 (EurObserv'ER 2005).

A vast majority of these systems provide only domestic hot water. Space heating, however, which require per house a greater area of collectors, account for about half of the total collector area in Austria and Switzerland, against around 20% in Germany and other countries.

Almost all new single-family houses in Sweden are equipped with exhaust-air heat pumps (about 4000 per year by 1997), and another 5-10,000 per year are installed in Germany.

Figure 1: Cumulative Capacity and Annual Energy Output



Source: Weiss et al, 2006

The overall contribution of solar active systems (not including heat pumps) has been estimated at 68 TWh_{th} for the world in 2004. As shows figure 1, this contribution to the energy needs is far greater than that of solar electricity, but only slightly greater than geothermal and lower than that of wind power, despite a greater installed capacity.

3.3 Solar heating for industrial processes

Heat represents about a third of the "useful" energy in the agriculture and industry sectors. However, only 85 industrial solar heat process installations have been identified worldwide, with 25 MW_{th} of capacity.

While some processes require very high temperatures, such as melting metals, others require medium temperature heat, especially in food, chemical and textile industries – often important economic sectors in developing countries (see figure 2). Moreover, one of the most promising applications for active solar heating worldwide is the drying of agricultural products. In Switzerland hay drying is done with unglazed solar collectors. Desalination is another important area of application, as water scarcity often hits areas with high solar insulation. There is a wide variety of stationary collectors (not tracking the sun) with selective coating and excellent insulation can reach 90°C or more with good efficiency.

Figure 2: Processes and Temperature levels

Processes and Temperature Levels

Industrial Sector	Process	Temperature Level [°C]
Food and Beverages	Drying Washing Pasteurizing Boiling Sterilizing Heat Treatment	30 - 90 40 – 80 80 – 110 95 – 105 140 – 150 40 – 60
Textile Industry	Washing Bleaching Dyeing	40 –80 60 – 100 100 – 160
Chemical Industry	Boiling Distilling Various chem. Processes	95 – 105 110 – 300 120 - 180
All Sectors	Pre-heating of Boiler Feed-water Heating of Production Halls	30 – 100 30 – 80

Source: AEE-Intec

Higher temperature solar heat requires concentrating solar rays and sun tracking. Whilst state-of-the-art parabolic trough collectors for solar thermal power plants can reach 400°C with high efficiencies, the majority of industrial process heat is consumed at temperature below 250°C and above 600°C. Therefore, smaller collectors, that could possibly installed on roofs, and optimised for temperatures up to 250°C are under development. High-temperature concentrating solar collector, possibly installed on a roof, can reach up to 400°C. They can typically be used for various industrial processes (compare Fig. 2), absorption cooling, desalinisation and water purification, as well as secondary space heating and domestic hot water uses. The high temperature range will require point focussing collectors, like parabolic dishes or solar towers. Their application for industrial process heat may be considered an option for the far future.

Less important from an energy standpoint are the industrial or research devices, such as the solar furnace at Odeillo (France), that are used in particular to test materials' resistance to very high temperatures. From this experience simple solar concentrating ovens are being developed for craft industry such as pottery in Morocco (Eudeline, 2005). The global energy contribution may remain small, but such tools may prove useful to combat deforestation and reduce in-door pollution – as is the case with solar cooking.

3.4 Solar cooking

Solar cookers allow preparing meals from mid-day to evening. Some are simple boxes with one glazed top; others use aluminium sheets to concentrate the solar rays and reach higher temperatures. The main purposes are to avoid deforestation, save time currently spent in gathering biomass, and alleviate health effects of burning biomass (or coal) in inefficient devices, especially in developing countries. They are usually cost-effective – their cost is "negligible when spread over 15 years or more" (Narayanaswami 2001). They could thus contribute to eradicate energy poverty in providing rural and urban poor with an effective substitution to their greater energy expenses – cooking fuels.

4. Barriers to Diffusion

Barriers to the diffusion of solar thermal technology can be ranked in three main categories – technical barriers, economic barriers, and other barriers including legal, cultural or behavioural barriers. The distinctions between these categories are not clear-cut, however.

4.1 Technical barriers

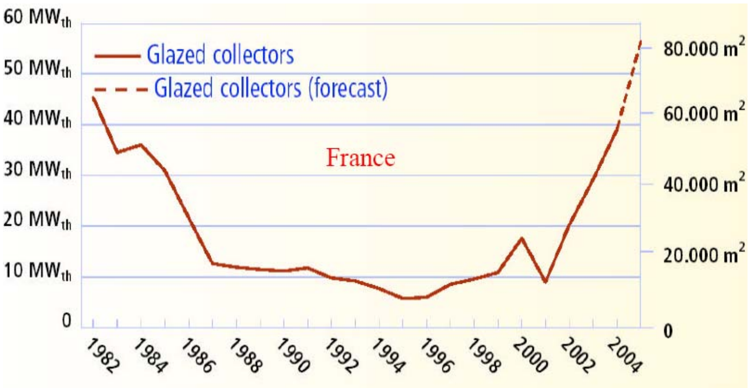
Solar thermal technologies have been considered and developed over decades. Although most technical problems met have been fixed, they have a long history of disappointing customers with poorer-than-expected performances. For example, thermal losses from heat storage have appeared being up to five times greater than originally expected. Counter-examples in the 70s and 80s have been numerous and in many markets have contributed to public distrust of the technologies.

In some cases, the disappointment also had to do with the interaction between the conception of systems and people's behaviour. For example, it is a common scheme that back-up heat is provided in the storage tank itself by an electrical resistance, not an instantaneous back-up heater. In the early days, if the hot water tank was emptied in the evenings, cold water refilled the tank and the electric heater worked overnight to heat the water. If there was no water draining in the morning, then the daytime solar input was wasted – and the customer saw little savings on its electricity bill. If, on the contrary, the water tank was emptied in the morning, then the solar input accumulated over the day and the storage tank kept the water hot over the night till the next morning. To maximise solar inputs thus was requiring householders to turn on and off the back-up electric heater depending on the weather forecast and their foreseeable hot water needs – or modify their bath or shower habits. State-of-the-art systems now build upon the stratification of temperatures in vertical storage tanks to alleviate much of these effects and cover by solar energy as much water heating loads as possible. Some use "smart tanks" and/or "low flow" concepts to further increase that coverage (Furbo et al., 2005; SHC, 2006). Others, notably in North America, use a solar preheat tank that is connected to a separate auxiliary water heating tank.

Most disappointments, however, happened as a result of the lack of competence and knowledge of planning engineers for complex systems and many installers – even for simple systems. Even if they use quality collectors and products, systems may not work properly if not installed carefully – and this requires a different knowledge than installing other water heaters, not to mention central heating systems.

An indication of these early difficulties can be found in the schedule of installations of glazed collectors in France from 1982 to 2004, on figure 3. Other factors, however, played a role, and to begin with the fall of world energy prices. Still, the period saw real public support to the diffusion of solar water heaters. The lack of confidence following an early start based on a population of incompetent installers of not fully mature solar products has likely contributed to the reduction in yearly installation.

Figure 3: New solar collector installation in France



Source: ESTIF 2005

After decades of development, most of the technical barriers have been fixed, at least with respect to the basic components of the systems. Theories for optimal design and sizing have been elaborated and computer tools designed – so most remarks made in this section in fact translate into cost issues. The one technical barrier that subsists is the lack of trained and competent installers in most markets. Another barrier that certainly relates to technical barriers is simply the fact that the public ignores that has just been noted – most products are now technically reliable. And it takes little time, in most countries, to householders investigating the possibility of installing solar water heater to notice the lack of competent installers.

Finally, another technical barrier to raising the contribution of solar water heating to the overall heating needs of households, and making their installation more profitable, might be the incapacity (frequent in Europe, much less so in North-America) of appliances such as washing machines and dish-washing machines to work with a source of (solar) hot water as well as a source of cold water.

All the points mentioned above mainly hold for production of domestic hot water. Main technical barriers for a widespread application beyond hot water production, i.e., for heating, cooling and industrial process heat are still on both the component and system level. For a broader application of solar heat for house heating fundamental R&D on storage materials and concepts is needed. For application in cooling and air-conditioning of buildings mainly the system level has to be worked out far more in case of large systems (commercial buildings, offices, hotels etc.). For small application in the residential sector proven components, i.e. small scale heat driven chillers and/or air handling units have to be developed and proven system concepts have to be developed and tested. For industrial process heat reliable, stagnation-safe medium temperature solar collectors working in the temperature range of 80-250°C are needed. The same collectors are also beneficial for application with heat driven cooling and refrigeration technology.

4.2 Economic barriers

Efficiency, capacities, output

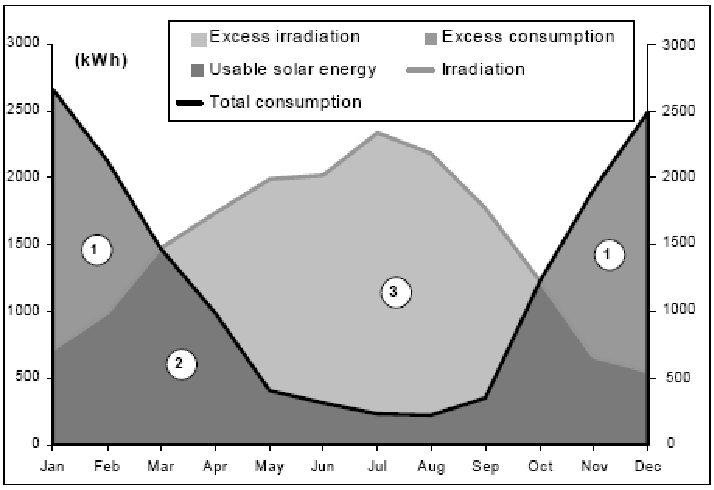
The annual specific output of an individual solar thermal system seems low by comparison with other intermittent renewable energy systems. Depending on the location, solar thermal collectors have an annual output equal to their rated capacity multiplied by less than 1000 hours – and more often 500 to 750 hours. PV is generally considered delivering an amount of energy equal to its peak capacity multiplied by 1000 hours per year, while CSP plants and wind turbines deliver their rated power during 2000 to 2500 hours or more per year.

The problem is obvious with respect to space heating – the resource is greater in summer when the demand is null, and lower in winter when the demand is the greatest. To some extent this remains the case for sanitary hot water – even if the consumption of hot water at a given temperature were constant in all seasons, the energy required to produce it is greater in winter, as water from outside is colder.

Figure 4, which is typical for the Northern hemisphere, shows that dimensioning a solar thermal system requires a trade-off between excess solar heat in summer and the size of the winter contribution. While short term storage is useful to face changing weather conditions, a means to expand the use of solar heat for space heating might be the ability to store the heat from one season to another – an area of research and some demonstration projects, but not yet an ensemble of mature technologies. Another option is to use the solar heat during the off-heating season for cooling application by using heat driven cooling technology. Thereby the operation hours of the solar system may be increased significantly (depending on the climate) and replace electric power consumption used for operation of vapour compression cooling technology.

The trade-offs might be different if one looks for economic optimisation or if one is willing to get a higher rate of coverage of heating load from the sun and a longer period without any fossil fuel back-up, even beyond what the economic optimum would be. The Dutch and German markets are sometimes mentioned as representatives of these two different attitudes.

Figure 4: Usable solar energy



Source: IEA-SHC Task 26

According to Rantil (2006) the average cost for solar heat was in 2000 about 130 EUR per MWh for solar domestic hot water systems. This is cheaper than electricity in Denmark, approximately the cost of electricity in Austria, Germany, Italy, Netherlands and Japan, but more expensive than electricity in other industrialised countries (IEA Statistics, 2005) – and more expensive than heat from natural gas in urban areas. For solar combisystems the cost is about 160 to 270 EUR per MWh depending on the size of the system – seemingly competitive with electricity in Denmark only. The IEA (2006a), however, reports a price of 295 euro per MWh for combisystems in Germany. Rantil expects these costs to go down by 2030 to 50-80 EUR per MWh for solar hot water systems, 100 - 140 EUR per MWh for combisystems, and 30 - 50 EUR per MWh for large-scale applications (>1MWth) like district heating and industrial applications.

Solar heat costs seem to be much lower, however, in China. About a thousand companies market effective monobloc thermo siphons for domestic water heating, mostly using modern evacuated tubes and following a design developed at New South Wales University by Professor Graham Morrison and his team. They cost less than 200 EUR, thanks to low labour costs. While this low cost is certainly one reason for the rapid growth of the Chinese solar thermal market, the difficulties encountered by the alternatives – from intermittent electricity supply to in-door polluting coal burning – largely contribute to this success.

In fact, costs vary greatly also according to climate conditions, requiring more or less complex installations. In Greece a DHW thermo-siphon system for one family unit of 2.4 m^2 collector and 150 l tank costs EUR 700. In Germany, where solar radiation is lower, a system of 4–6 m^2 and 300 l tank, fully protected against freeze, costs around EUR 4500. Water heating systems are thus more profitable in sunny and hot areas.

This is not the case with active solar space heating. In warm and sunny places output of solar systems is bigger but largely wasted as heating loads are small and the cold season short. In colder areas a lower output is better used as heating loads are higher and the cold season longer. The same solar system that get 40% savings on heating expenses in north France, i.e. EUR 730 to EUR 900 yearly revenues, provide in south France 80% savings, i.e. EUR 120 to EUR 180 yearly revenues only. (Lenormand, 2005).

Absent heat storage, the best conditions are usually found in the mountains, where sunshine may combine with cold outer temperatures. In collective systems with storage, 30 to 95% of total annual heating and hot water requirements can be provided under German conditions, though at relatively high costs (from 160 EUR to 420 EUR per MWh_{th}).

Cost is also a significant impediment to solar air conditioning, as capital costs are several times those of conventional electric vapour-compression systems. Costs per unit energy are reduced if a solar thermal collector is designed to be used for both summer cooling and winter heating. The reversibility for solar cooling systems is more or less compulsory to make it economically sustainable.

Solar active space heating is significantly cheaper for new constructions than for retrofitting. This is even truer with respect to passive solar architecture. Letting the sun heat buildings in winter and letting daylight enter them to displace electric lighting, may be the least cost solar energy forms. Cost estimates, however, are scarce, probably as a result of the great variety of situations. According to the EU Commission (1997), "*experience in Austria has shown that passive solar construction increases overall dwelling costs by less than 4% while achieving 75% reductions in heating energy*".

Not only the levelised cost of (active) solar heat is hardly competitive without subsidy in mature energy markets where alternatives are abundantly supplied; perhaps more importantly, its different structure is itself problematic, as it requires important up-front expenses. The benefits due to lower running costs are not always duly accounted for, mainly due to the very common use of the "pay back time" criteria for selecting investments. All economic textbooks note that this criterion is the worse possible, for it ignores completely the economic life of an investment after its pay back time. Its only merit is simplicity but it is most often misleading. For example, it leads to prefer an investment with 2 years pay back and 3 years lifetime to an investment of 3 years pay back but 10 years lifetime, while the latter would be more profitable with all credible discount rates. Its use is thus particularly unfavourable to long-lived investments such as most energy savings, including solar thermal technologies. Not only households count amongst its victims, but also many enterprises, small or large, as reveals a study of the barriers to solar process heat (Carwile and

Hewett, 1975); in 14 out of 15 cases, the company used the pay back time criterion for selecting – or indeed rejecting – these investments.

Customers, especially the less wealthy, may have high implicit discount rates, i.e. a strong preference for the money they have today over the same amount of money tomorrow. Initial cost may thus be a real deterrent. An extreme example is that of solar cooking. For example, the commercially available box cooker in India costs at the very least Rs.1500 (i.e., USD 32). *"The payment is up front. Spread over a period of 15 years or more the cost is negligible but that argument does not impress"* (Narayanaswami, 2001). Very poor people have an economic horizon limited to the day or the week; they can only consider investments with almost immediate returns.

Another problem arises from the variety of discount rates by different economic agents Suppliers of other energy forms, especially electric utilities, often use lower discount rates reflecting their easier access to capital. Thus, arbitrage between fuel or electricity supply, on the one hand, and fuel savings, including due to solar thermal technologies, is often unduly skewed in favour of fossil fuels or electricity supply. Some utilities have recognised the value of the reduction in peak demand arising from solar hot water programmes in avoided production and transmission capacity (see, e.g. US DOE, 2002).

Two important issues must also be considered as impeding solar thermal development: 1) the frequent lack of internalisation of environmental externalities, notably air pollution and climate change in fossil fuel prices at household level, and to a lesser extent in fossil-fuelled electricity prices. 2) The direct or indirect subsidies to other energy sources, notably electricity and natural gas, still very important in some countries, notably developing ones. On both sides, the situation might be slowly improving, though; Policy makers designing means to get around the economic barriers, at least temporarily, will also consider the potential for cost reduction when the industry expands in a market and raises the performances of its products thanks to the experience gained in the field – i.e. economies of scale and learning-by-doing processes.

Another important barrier to the diffusion of solar thermal technologies is the importance of the tariffs on solar water heaters, which surpass 20% of their value in some WTO member economies. Bound rates (resulting from negotiations and fixing an upper limit to applied rates) exceed 20% in over 50 WTO members, including several OECD countries. (Steenblik, 2006).

4.3 Institutional, legal and behavioural barriers

The most important barrier in this category is probably the "split incentives" problem, which arise for solar thermal technologies both in the new construction and rental markets. Property developers and buildings owners renting their properties have little incentive to invest in energy saving equipments, including solar thermal devices, while the returns on investments will go to actual occupants. In theory it is possible to conceive of financial arrangements between builders and homeowners or between landlords and tenants where the costs and benefits of energy efficiency investments are shared. In practice this is very difficult to achieve due to inadequate information, high transaction costs, and market inertia. Split incentives also exist in large companies or administrations, when resources for investment and running costs are separated and the decision maker may not benefit from the fuel savings resulting from investment in solar equipment.

Other institutional barriers arise in existing collective dwellings. In case any flat owner has its own system it would be a coincidence if every one feels the need to modify its installation to open it to solar heat, and a chance if a strong majority decision (if unanimity is not required) could be adopted. Moreover, some flats might be rented, in which case the "split incentives" issue for some may become a barrier for all. If one dweller in the building wants to act in isolation, the installation of a single device may become technically very complex, for example in a multi-storey building, and will still require permitting from a majority of co-owners. Therefore, experts consider solar technologies for multi-dweller buildings generally possible only in new constructions and complete retrofitting processes.

Legal barriers vary greatly from country to country, but also often following lower territorial divisions. In many places, following local or national regulations, either ground mounted or roof mounted installations, or both, will require some kind of permits. Even when permits are given, they may create delays and have costs, from permit fees to lawyer fees. Permit agencies often have very little knowledge of solar technologies – if any, and may place unnecessary conditions on projects, adding to the complexity and cost of the installation. The diversity of local requirements just mentioned is itself another barrier, as it may prevent solar contractors providing systems in multiple jurisdictions from learning by doing in expediting procedures Often, permits are simply refused, solar systems being considered not compatible with existing community aesthetic standards and architectural requirements. In some cases, permitting authorities (or neighbours) believe that glare is a significant issue associated with solar panels – while solar panels absorb over 90 per cent of the light received. (Feeney and Neumann, 2004).

Finally, some barriers relate to behaviour. This of course includes the lack of awareness of the current status of the technology and its possibilities. This may also include, however, the reluctance to manage a slightly more complex system, which may need, as seen above, a little attention to be effective, or the (mis)perception that intermittence may lead to a lower comfort for either space or water heating, or some changes in habits.

The diffusion of solar cookers, for example, for all its potential benefits, certainly requires people to modify their cooking habits. This has proven one important barrier, according to Narayanaswami (2001): *"A commonly cited impediment is slow cooking and inability to cook outside of sunshine hours. This may be real in some homes where the routine of work does not permit cooking during daytime but not all homes are in this category. Also access to sunlight may be difficult in some homes, which also is understandable. But more often these excuses are offered not because they are real but as a cover for a reluctance to try something new, to break from existing habits."* Indeed, after decades of efforts including subsidy programmes solar cookers have not proven successful in individual homes; most reported successes relate to one or another sort of "public cooking", where a professional is in charge.

5. Policies to Overcome Barriers

All IEA Member countries and most developing countries have undertaken a range of policies to support solar thermal technologies. They can be classified in three main categories: support to research, development and demonstration, support to market deployment, and regulations.

5.1 Support to research, development and demonstration

Research, development and demonstration policies aim at alleviating technical barriers and reducing costs altogether in improving materials, components, system design and tools for installers and users. Although the technology is now mature in its simple applications, improvements remain possible and new areas remain to be essentially investigated, such as solar heat for crop drying, industrial processes, or combined PV and thermal collectors. Much also remains to be done in the area of passive architecture for reducing heating and cooling loads alike.

Many industrialised and developing countries have policies to support research and development efforts. However, all indicators show that these policies are very small and weak. Not only renewable energy in general gets a small share (7.7% in the last 15 years) of energy R&D budgets in IEA member countries, but solar heating and cooling represents only 0.55% against 2.68% for solar PV (IEA, 2006a). Indeed, wind, geothermal energy and concentrated solar power (CSP) are given even less, suggesting that public R&D funding is somehow inversely proportional to the energy potential. In a recent brochure on solar R&D by the US DOE, PV is given 14 pages; solar thermal technologies (including CSP) are given 2 pages.

Since 1977 the International Energy Agency's solar heating and cooling "implementing agreement" has offered a framework to the international co-operation in this area, greatly enhancing the global efficiency of the R&D spending in each country. It involves researchers from 21 countries. Almost 30 tasks or working groups have now completed their work, producing a considerable amount of knowledge and tools contributing to the development of solar thermal technologies and markets (see www.iea-shc.org). On-going tasks include performances of solar façade components, solar sustainable housing, solar crop drying, day lighting buildings in the 21st century, advanced storage concepts for solar thermal systems in low energy buildings, solar heat for industrial processes, testing and validation of buildings energy simulation tools, and combined PV/thermal systems.

5.2 Support to market deployment

Support to market deployment may include a wide number of policies, from outreach and awareness-raising to training to certification of components and systems at national or international levels to various financial incentives to reducing import tariffs.

Outreach and training

Outreach programmes are necessary to raise awareness of potential customers of the possibilities of solar thermal technologies – especially to inform them of the state of maturity reached by solar water heaters, combisystems and others. Demonstration with good performance by example helps a lot.

Training, especially of engineers and installers, is also a key component of comprehensive support programmes to market deployment, as the lack of solar competence of most professionals in the energy service companies, heating installers, architects and building developers is an important barrier to diffusion. This training should not focus only on the technical aspects. Sales and marketing people, for example, should be able to use other economic criteria than the sole "pay back time" to support the profitability of their products.

Training of professionals is even more important with respect to solar passive architecture as it does not rest on the diffusion of standard systems but more on the early incorporation of solar capacities in the design of buildings. One interesting example is the yearly contest "solar homes and buildings" run by the French NGO Observ'ER with the support of its industry and governmental partners.

International support through the Global Environmental Facility (GEF) has been provided for solar thermal technologies, only in a few developing countries, notably Morocco and Tunisia. The number of solar water heaters in Morocco has dramatically increased from about 20 700 in 1998 to about 111 300 in 2004. The jump can partially be attributed to a GEF project, implemented by the United Nations Development Programme (UNDP). Because the analysis of the existing market showed that its growth was hindered by the low quality and reliability of previous solar water heaters, the project has been designed to focus on improving product quality and reliability. The project is training governmental agencies and private firms to promote, evaluate, and install solar hot water systems. It is helping the country to develop norms, standards, and testing procedures to ensure that all solar water heaters sold and installed in the country are built to meet the highest international standards. Moreover, the project is introducing assemblers and manufacturers to improved standards; training architects and engineers to apply the standards and procedures; and developing codes of practices for constructors, installers, and plumbers. (GEF, 2005).

Certification, guarantees, solar energy service contracts

After the disappointments encountered in the 80s, it has been deemed necessary to provide customers with greater level of confidence in the maturity of solar thermal technologies. This is why many governments but also industry associations and regional authorities (US States, Provinces and the like) have developed certification systems of both collectors and full systems.

However, the diversity of these schemes has become itself a barrier to the competition and circulation of products across borders – a trade barrier. Hence there is now a search for greater harmonisation of certification schemes. For example, in Europe recent efforts of the European Solar Thermal Industry Federation (ESTIF) with the European Committee for Standardisation (CEN) have led to the creation in 2003 of the Solar Keymark, claimed to be *the* quality label for Solar Thermal products in Europe. It certifies compliance with the relevant EN standards for solar thermal products: EN 12975 (solar collectors) and EN 12976 (factory made system). Only its voluntary recognition by industries and national governments, however, will prove its success. Currently 17 EU countries have recognised the Solar Keymark. Alongside numerous European companies, at least one Chinese and one Japanese company have got the Solar Keymark for some of their products.

Another way to make customers more confident about the technology is the guaranteed-result schemes or solar energy services, especially for large installations. With performance guarantee schemes the building owner also owns the solar plant but the solar company guarantees the performance of that plant. If it does not perform to plan, it results in contract penalties for the solar company. With solar energy services contract customers pay only for the solar energy produced – the solar company build and operate the plant, making the minimum realistic project size 300 m^2 according to Holter (2005). Indeed the establishment and use of such schemes rests on industry initiatives and does not require public intervention – except for ensuring the respect of contracts.

Financing, subsidies and fiscal incentives

Energy service companies may also offer third-party financing to overcome the "split incentives" barrier. They would finance the solar investment and receive part or all the fuel savings for the time necessary to recover the investment plus profit margin. This scheme is particularly useful in administrations when funding for investment and funding for running costs are not fungible at the decision maker's level.

Most industrialised country governments have put in place policies to support financially the dissemination of renewable energy technologies. Numerous reasons might justify such policies, at least for some time, including 1) the perception of the necessity to pay for some "external" benefits such as greater energy security and lesser environmental impacts of clean renewable resources over dirtier and exhaustible resources; 2) the hope that learning investments will improve the performance and reduce the cost of nascent renewable energy technologies, making subsidies transitory only; 3) the necessity to reduce the distortions that may arise from cost structures differing among energy sources and implicit discount rates differing between the supply and demand sides (for a fuller discussion see, e.g., IEA 2003, Chapter Four, *A Market Barriers Perspective*, pp. 63-79)

Tax credits and grants constitute usually the core of the public policies to support the dissemination of solar thermal technologies, alongside qualification of materials guaranteeing performances. One the most ambitious programmes might be the German "*Market Incentive Programme*" with a budget of approximately 180 M EUR per year with investments grants for small solar thermal systems.

In Tunisia, the USD 7.3 million GEF grant mentioned above has enabled the financing of a direct subsidy to solar water heaters at 35% of their costs, and accompanying measures aiming at ensuring the quality of the products and associated services. The scheme has proven effective but the volumes have remained insufficient to drive sufficient cost reductions to permit the market to survive the end of the subsidies. A subsidy at the same level was thus reinstated by the Tunisian government in 2004, with some support from UNEP in its Medrep programme and the Italian ministry for the environment (AMNE, 2006).

Governments' subsidies do not only reduce up-front expenditures; they also strengthen the willingness of householders and others to turn to solar by suggesting first that the technology is working and second that turning to solar really has some attributes of a public good. One of these – beyond directly increasing energy security and reducing pollution and greenhouse gases – is to accelerate cost reductions of nascent climate-friendly technologies through early market deployment and learning-by-doing processes (Philibert, 2003). Indeed, learning investment: the cost reduction history for solar water heating systems and for the newer combi-systems shows average values of system costs (including taxes and installation) shows that in Austria and Germany, over the past ten years, each doubling of the market led to a 20% reduction in the installed cost (IEA, 2006a). The effect and the cause might be intertwined, though.

While subsidies are effective, they require significant amounts of governments' money – a scarce resource. While the subsidy rates may decrease when costs diminish, the total expenditures may still increase as the markets expand. The risk is that the scheme may not be supported long enough to make a difference in the emergence of sustained and mature markets – "stop-and-go" policies have proven disastrous for emerging markets. Other financial mechanisms, directly linked to energy consumption (green or white certificates) or to emissions (carbon trading) may have greater legitimacy and prove more robust over time.

Green certificates

Feed-in tariffs or (possibly tradable) obligations made to electric utilities to increase the share of renewable in their energy mix, may prove more robust than plain subsidy schemes as the former ultimately make energy end-users pay the bill – not taxpayers. But low-temperature solar thermal technologies do not deliver power, but heat. While many countries (or States or Provinces) have created incentives schemes for increasing the production of electricity from renewables, most of these schemes do not provide any incentive for solar thermal technologies.

There is, however, at least one notable exception: Australia's mandatory renewable energy scheme, which requires electricity generators to produce up to 2% of their output from renewable sources, or to buy renewable energy credits from other generators or from products displacing electricity, such as solar water heaters. Only systems complying with the Australian standard can be credited. The number of Renewable energy credits (RECs), each equivalent to 1 MWh, is computed at the time of the installation depending on its size and likely performance, itself depending on the climatic zones; it represents the electricity saved over ten years – a period shorter than the expected life time to avoid the intricacies of using discount rates to compute the present value of the future savings. RECs obtained from installing solar water heaters range from 14 to 40 per system.

The system was put in place 2001. It has proven effective for solar water heaters with more than 118 000 systems as of 1st January 2006, representing 26% of the total RECs registered, second only to hydro. Transactions costs have been small, as 99% of RECs from solar have been registered and sold by 40 authorized "Agents" – mostly system installers. Although the exact value of the subsidy these RECs represent varies, the solar heaters have proven relatively insensitive to price variations (Rossiter, 2006).

White certificates

Although the EU countries have not included solar water heaters in their renewable electricity incentive schemes, some have developed energy saving certificates or "white certificates" systems, which may more easily provide incentives for solar thermal technologies

Under white certificates system, producers, suppliers or distributors of electricity, gas and oil are required to undertake energy efficiency measures for the final users that are consistent with a pre-defined percentage of their annual energy deliverance. White certificates are given to the producer whenever an amount of energy is saved whereupon the producer can use the certificate for their own target compliance or can be sold to (other) obliged parties.

At least the French and Italian white certificates explicitly recognise solar water heaters as energy savers eligible for white certificate crediting. The French system, for example, distinguishes three continental zones and overseas territories, as well as individual or collective systems. The standard calculation considers 15 years life time for continental individual heaters then applies a discounting factor – MWh saved in future years have a lower present value than MWh saved this year. The extension to active or even passive solar heating may not be precluded in principle but may be handicapped by transactions costs unless standard procedures and calculations could be set up.

Carbon trading and CDM

Water solar heaters, but also solar crop drying, solar process heat or even solar heaters, could be candidates for eligibility under the clean development mechanism, or as joint implement projects or project-based offsets when carbon trading systems allow them. The difficulty may lie in transaction costs for the small systems or even most "large" systems for this industry, which may remain too, small to easily get through these mechanisms not entailing excessive transaction costs.

For example, solar water heaters in six developing countries – Barbados, Brazil, China, India, Mexico and South Africa – have been considered by Milton and Kaufman (2005). Their analysis, based on averaged water consumption, common heating systems and, where applicable, electricity mix, suggest that single family-scale solar water heaters would save from 0.75 tonnes of CO_2 per year in China to 3 tonnes in the Barbados. With the assumption of a crediting period of 14 years and a price for CERs of USD 5 per tonne of CO_2, they found that the potential CER revenue would cover from 8% of the investment costs in Brazil and Mexico to 30% in India. However, only projects involving at least 10 000 to 40 000 water heaters could, for example, satisfy the World Bank's Community Development Carbon Fund criteria for supporting "small-scale" project, i.e. the generation of at least 30 000 tCO_2-eq per year.

Demonstrating additionality and establishing baselines may not present great difficulties and would likely be uncontroversial for projects in most developing countries. China might be different, though, as China currently is the world largest market for this technology. Additionality may thus be more difficult to establish. In other countries, to the contrary, revenues from the CERs may be too low; if not it should probably require an investor to pre-finance the CERs to make the equivalent subsidy covering the up-front expenses at the time the installation of the solar water heaters.

As of June 2006, one solar thermal project was registered as CDM project. The solar cooker project Aceh 1 was first developed by the German and Indonesian NGOs Klimaschutz e.V. and PT Petromat Agrotech then supported by the aluminium company Alcan. It aims at installing 1000 solar cookers in Indonesia. Each solar cooker, locally manufactured, will prevent the emission of 3.5 tonnes of CO_2 per year in replacing non sustainable fuel wood use. In total the project will thus over seven years be credited of 24 500 tonnes – well below the level considered by the World Bank as minimum to cover transaction costs. The total investment and running costs of the projects - 315 000 EUR – would anyhow be recovered only if the price for CERS reaches 13 EUR per tonne of CO_2.

Procurement

Co-operative private or governmental technology procurement can have numerous advantages over individual purchases, such as reducing time and costs, reducing risks for manufacturers and ultimately accelerating the innovation and dissemination processes for the benefit of the participants and beyond, for the general public. Westling (1997) provides for several examples of energy end-use projects, using the technology procurement method in Sweden that led to energy reductions of 30-50 per cent.

Co-operative procurement can be international. The IEA Solar Heating and Cooling "implementing agreement" run from April 1998 to March 2003 its "Task 24", which aimed to increase the use of solar water heating systems by encouraging coordinated large-scale purchasing. The objectives have been to reduce marketing, distribution and hardware costs, as well as to improve system performance. The procurement efforts have focused primarily on small domestic active solar water heating systems, but have also applied to larger commercial systems. Substantial cost and price reductions with 7 – 30 per cent have been reached.

Unfortunately, but significantly, only six countries took part in Task 24: Canada, Belgium, Denmark, The Netherlands, Sweden and Switzerland. Some of the projects initiated by the SHC Task 24 have been continued under the "Soltherm Europe Initiative", which gathers 11 European countries (Westling, 2003)

There remains probably a vast area for procurement to play an important role in the development of solar thermal technologies, at both domestic and international levels. For example, the Canadian Solar Industries Association suggests an expansion of the existing Government's Green Energy Procurement Commitment that would include a commitment to purchase 20% of government's heating needs from renewable technologies, stating that this would make a significant impact on the solar thermal industries. This could combine with "*high profile demonstrations on government buildings*", aimed at encouraging consumer demand for solar energy equipment through leading by example.

At the international level, a new era of co-operative procurement efforts, leading to "sharing the learning investments" (Philibert, 2004b), could be initiated on a much larger scale than the former SHC Task 24 as a result of a growing awareness of the importance of solar thermal technologies as a means to mitigate climate change.

Reducing tariffs

Reducing import tariffs would benefit consumers all over the world, and the most effective producers. This may particularly benefit manufacturers in developing countries such as China. The overall economical effect in industrialized countries main still be positive for the thermo-solar industry as a whole, for an important part of the value is created by the installing work. A decrease in component costs would drive an increase in installation rates and activities, which is particularly labour intensive and would more likely increase than decrease employment rates in the solar industry in all countries.

5.3 Regulations

Governments that wish to strengthen the use of solar thermal technologies must first act to identify and remove, as appropriate, the legal barriers impeding their development. Permitting, when necessary, must be streamlined and simplified. They may also usefully adapt and update their existing legislations that protect their citizen's "solar rights", i.e. prevent new building to excessively deprive existing buildings from sunlight. The most recent technological developments, aiming at "hiding" the solar collector in the roofs or façades or even gutters may also provide new answers to aesthetics concerns or regulations (see, e.g., Rigaud, 2006).

Some of the financial incentive schemes described above ultimately rest on some obligations made to increase the use of renewable energy or reduce energy consumption – or emissions of greenhouse gases. But these do not directly target solar thermal technologies, and most of them ignore them entirely. Similarly, some recent building regulations, by imposing energy consumption performances, may provide indirect incentives to solar passive architecture or solar active water heating or space heating systems. For example, the EU Directive of 12 December 2002 on energy performance of buildings simply mentions solar active and passive systems as being part of the general framework for calculating the energy performances. Some of its national transcriptions, however, may have done a small additional step in specifying, for example, that water heating and heating systems of new buildings should be "solar ready", i.e. easily completed at a later stage with solar collectors.

Others have gone much farther, starting with Israel, where a regulation published in 1980 compelled the use of solar water heater for any new residential building not higher than 27 meters. As a result, about more than 80% of the roofs of residential buildings in Israel are covered by solar heaters, and three quarters of the solar heater industrial production goes for replacement.

In 2000 the municipality of Barcelona adopted an ordinance requiring all new buildings or buildings undergoing heavy renovation to have a solar collector system capable of covering at least 60% of its needs in domestic hot water, with the condition that this be a minimum of 1860 litres of water per day. Less than four years later the surface area covered by solar collectors had jumped from 1650 m^2 to 20 000 m^2, and the objective set for 2010 of 80 000 m^2 seemed within reach. Following that example, twenty municipalities in Catalonia soon adopted similar ordinances. In 2002, Seville and Pamplona, in 2003 Madrid, followed suit. (*Renewable Energy Journal*, 2004).

These experiences were certainly instrumental in the Spanish government's decision in March 2006 to issue the first European law in Europe, and probably the second in the world after Israel, that requires new and heavily renovated buildings to cover 30 to 70% of their domestic hot water demand with solar thermal energy. This "technical building code" approved by a Royal Decree sets minimum standards, which would not prejudice the application of more stringent requirements from existing or future solar ordinance from municipalities or other sub-national authorities.

Certainly the concept of imposing solar thermal technologies by law may be challenged. Why should governments make technical choices, while setting performance standards or emissions targets would directly address the issue of the formation of public goods – air quality, low energy prices, stable climate – and alleviate market failures such as the "split incentives" described above? One reason might be that, although it is expressed in terms of performance, a solar requirement is much easier to monitor than a very general requirement on the performance of buildings. Other justifications arise from the large cost difference between solar equipment in new buildings and retrofitting, and the necessity to overcome the split incentives barriers. Finally, another reason might be the necessity to develop early markets for still developing technologies up to the point where markets will be mature enough to carry them by themselves.

While straight regulation may not be the only way to help the diffusion of solar thermal technologies, it seems to be a rather powerful tool – provided it includes a minimum quality requirement. This is probably the reason why the EU Commission, having realised that its current legal system on renewables has left solar thermal technologies, as well as heat from biomass burning and geothermal, in a vacuum, is now considering closely the establishment of a directive on renewable heating and cooling.

6. Conclusions

Low temperature solar thermal technologies have costs that vary greatly. They range from already cost-effective applications, especially for new buildings, to schemes more likely to become cost-effective when R&D efforts, economies of scale and learning by doing processes will have reduced costs. Market conditions also depend on the availability of the alternatives, as shows China's case. However, competing technologies may become more expensive, due to higher fossil fuel prices and economy-wide carbon externality costs. Beyond economic consideration effective policies seem to require a great variety of instruments to inform customers and train professionals. Removing trade barriers may also help.

It seems important to realise that all these barriers must be addressed simultaneously. Labelling products or training professionals will not work if the up-front costs are way too high. Subsidies will not work for long if customers can only access bad products installed by incompetent technicians. As stated by the IEA (2003), policy makers must combine a R&D deployment perspective, a market barrier perspective and a market transformation perspective: "*The R&D Deployment perspective focuses on the technical knowledge base and its interactions with deployment. It provides a rationale for learning investments and a future-oriented outlook. The market barriers perspective, grounded in economic theory, provides criteria for market efficiency and discipline in regard to the nature and extent of government interventions in the market-place. The market transformation perspective focuses on the practice of technology deployment, building upon the insights and techniques of the private sector and transferring this approach to the design and implementation of public policy. However, any one of the perspectives in isolation is insufficient*." The success may rest on the capacity of policies to reach a "critical mass", which includes the availability of trained and informed professionals and the experience of the broad public.

There is wide discrepancy between market maturities in countries that enjoy essentially similar economic and climatic conditions, which is reflected by widely different per capita contribution from solar thermal. Italy and France, for example, lag behind Austria, Germany and Spain. Austria has 30 times more solar heat collectors per head than Italy. This situation is set to change as new policies are being put in place, with for example a tax credit of 50% of the value of the solar systems in France. And a 2005 law obliges for the first time the energy ministry to plan for heat investments. Still, it will take time for the market to develop and the professionals to acquire the necessary competences. Ultimately, the differences in markets enjoying today similar financial incentives may rest on the age of these policies – although cultural differences may play a role too.

Stronger governmental policies to support renewable energy technologies have been put in place year after year in most industrialised countries and many developing ones. Still, policies to support solar thermal technologies lag behind in many countries. For example, the EU Commission has published directives for the promotion of electricity from renewables, for the promotion of bio fuels, and for the promotion of combined heat and power with dispositions to include biomass combustion – but not for solar thermal. Similarly, many countries and States have established renewable portfolio obligations for their electric utilities, but only Australia has included solar thermal as a means to comply.

Beyond or behind the barriers that have been mentioned here, there might be another barrier that prevents governments to adopt sound policies to support solar thermal technologies – that is the lack of awareness of its possibilities. This is reinforced by the lack of available information on the importance of heat demand as useful energy, as well as the role that solar thermal energy plays already, notably as passive solar contribution. Not only statistics, but also projections and scenarios performed by national or international agencies, tend to ignore them – or to mention them briefly but not integrate them in models.

Energy analysts indeed, and the computer tools they develop, manipulate primary energy sources, secondary energy forms such as fuels or electricity, and final energy uses. Bio fuels or wind power, or even PV, may find their ways in such frameworks. Direct heat from the sun, mostly used in decentralised forms, does not. Even co-generation or geothermal technologies, which provide heat in vast quantities that are sold to others and thus find their way in commercial statistics, are not put at the same disadvantage.

The EU, for example, has set ambitious objectives with respect to electricity from renewables. In its 1997 White Paper on a community strategy and action plan "Energy for the future" it has adopted three objectives: 10 000 MW of large wind farms, 100 000 PV systems, and 10 000 MW_{th} biomass installations. The possibility that active solar systems would represent 100 million m^2 in 2010 was briefly mentioned. The possible contribution of passive solar was not considered. Hence the European Renewable Energy Council (EREC), which gathers various renewable industry associations, laments that "*the heating sector is a neglected giant.*"

This remains largely the case in most countries, industrialised or industrialising.

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