Opinion paper

Perspectives for solar thermal applications in Taiwan

Keh-Chin Chang a, Wei-Min Lin b, Tzong-Shyng Leu a, Kung-Ming Chung a,*

a Energy Research Center, National Cheng Kung University, Tainan, Taiwan
b Department of Accounting Information, Tainan University of Technology, Tainan, Taiwan

HIGHLIGHTS

- The long-term subsidization for solar water heaters has lost effectiveness.
- Solar thermal applications include BIST, PV/T and industrial heating process.
- A performance-based subsidy policy should be implemented.

ARTICLE INFO

Article history:
Received 12 October 2015
Received in revised form 7 March 2016
Accepted 21 March 2016

Keywords:
Solar water heater
Building-integrated solar thermal
Photovoltaic/thermal
Taiwan

ABSTRACT

Taiwan has long depended on imported fossil energy. The government is thus actively promoting the use of renewable energy. Since 2000, domestic installations of solar water heaters have increased substantially because of the long-term subsidies provided for such systems. However, data on the annual installation area of solar collectors in recent years indicated that the solar thermal industry in Taiwan has reached a bottleneck. The long-term policy providing subsidies must thus be revised. It is proposed that future thermal applications in Taiwan should focus on building-integrated solar thermal, photovoltaic/thermal, and industrial heating processes. Regarding building-integrated solar thermal systems, the current subsidy model can be continued (according to area of solar collectors); nevertheless, the application of photovoltaic/thermal and industrial heating systems must be determined according to the thermal output of such systems.

1. Introduction

In 2015, Taiwan passed the “Greenhouse Gas Emission Reduction and Management Act,” in response to global warming which stipulates that by 2050, the total carbon emission must be reduced to less than 50% of the total emission in 2005 (approximately 245 million metric tons). However, Taiwan has long depended on large quantities of fossil energy for power generation, transportation, factories, and the agricultural industry; renewable energy (municipal waste, biomass, solar PV, solar thermal, and wind), which accounts only for 1.73% of the total energy production in 2014 (BEMOEA, 2015), is one of the vital options for achieving the carbon emission reduction target. Statistics released by the International Energy Agency revealed that the 2013 total global capacity in operation for solar thermal energy was 374.7 GWth and the energy produced was 314 TWh (Mauthner et al., 2015). Taiwan lies across the Tropic of Cancer and receives abundant sunlight, rendering it a suitable region for promoting solar thermal systems.

According to the “Renewable Energy Development Bill” of 2010, the Taiwan government has established the “Regulations for Incentive Subsidy for Renewable Heating” to promote the development of the solar thermal industry (Chang et al., 2011). Notably, the Energy Research Center at National Cheng Kung University has been authorized by the BEMOEa to organize an operation unit for the subsidy program since 2000.

Solar thermal applications in Taiwan are mostly concentrated in low-temperature systems, mainly solar water heaters (SWHs). Such systems do not track the sun and have temperatures less than 100 °C. Fig. 1 illustrates the annual installation area of solar collectors in the period of 1982–2015. During this period, the annual installation area of solar collectors from the year 2000 onwards reached 110,000–120,000 m² because of the subsidy policy implemented by the Taiwan government and several local governments, as shown in Table 1. Notably, the peak value in 2010 corresponds to a local subsidy program that was offered by Kaohsiung city government. From 2000 to 2014, the total area of installed solar collectors was approximately 1.5 million m². If the lifetime of a SWH is assumed to be 15 years, then 0.3 million SWHs are currently in use; the yearly saving is estimated to be 0.101 million kiloliters of oil equivalent, corresponding to a carbon...
The energy bureau in revising the solar thermal subsidy and for other energy. The results of this study can serve as a reference for the target businesses and industries that require large quantity of heat also an alternative. Furthermore, the solar thermal industry should thermal systems, building-integrated solar thermal (BIST) systems stalled on townhouses. To increase the domestic use of solar with high-rise buildings because such systems can be mainly in- stalled (Mauthner, et al., 2015). In Taiwan, national standards for solar collectors (the Chinese National Standards, CNS 15165-1-K8031-1) or SWHs (CNS 12558-B7277) have been enforced. The CNS 15165-1-K8031-1 is based on ISO 9806. In the period of 2000–2015, certifications of a solar collector or a SWH are required to file a rebate, e.g. the ratio of useful heat absorbed by a SWH to in- coming solar energy on solar collectors should be greater than 50%.

2. Solar thermal applications

Imposing regulations that require new buildings to employ a certain ratio of renewable energy is a common international de- velopment trend (Lau et al., 2012; Timilsina et al., 2012; Pablo- Romero et al., 2013 Abu-Baker et al., 2014). The U.S. Energy In- dependence and Security Act of 2007 stipulates that all new commercial buildings must reach zero net energy by 2030. From 2009, consumers purchasing SWHs certified by the Solar Rating & Certification Corporation are entitled to a subsidy greater than 30%. The Energy Performance of Buildings Directive stipulates that the energy for all new buildings in the European Union must be calculated and that according to the amount of sunlight received by various countries or regions, the energy consumption must reach a stipulated ratio of a building’s total hot water consumption. Moreover, this directive mandates that consumers installing solar thermal systems that have the SOLAR KEYMARK sticker can receive a 10–15% subsidy from their government. The renewable energy heating bill implemented by Germany in January 2009 states that the solar thermal system installed in a building must meet at least 15% of the building’s heating demand. Spain passed the new Technical Buildings Code in 2006, which stipulates that the solar fraction of all buildings must not be lower than 60%. For industries demanding hot water with temperature lower than 60°C, solar thermal systems must be able to supply at least 20% of the thermal demand. Japan has approximately 13 million town- houses and plans for 7.7 million houses to install SWHs in the future, with the expectation of reaching a target of 0.4 million yearly installations by 2020. In China, technical code for SWHs of civil buildings and compulsory national standard for energy effi- ciency are formulated, which is based on development of solar thermal industry, rather than the international standard (Liu et al., 2012). In 2013, the solar thermal systems in operation in China accounts for approximately 70% of the total global capacity in- stalled (Mauthner, et al., 2015). In Taiwan, national standards for solar collectors (the Chinese National Standards, CNS 15165-1-K8031-1) or SWHs (CNS 12558-B7277) have been enforced. The CNS 15165-1-K8031-1 is based on ISO 9806. In the period of 2000–2015, certifications of a solar collector or a SWH are required to file a rebate, e.g. the ratio of useful heat absorbed by a SWH to in- coming solar energy on solar collectors should be greater than 50%.

PV/T modules are other modalities of solar thermal application and can be primarily divided into four categories: PV/T modules with liquid collectors, PV/T modules with air collectors, ventilated PV modules with heat recovery systems, and sunlight-concentrating PV/T modules (Chow, 2010; Dubey and Tay, 2013; Othman et al., 2013; Higgins, et al., 2014). In addition, PV/T mod- ules can be subcategorized into glazed or unglazed groups de- pending on whether the top of such modules are with a glass

![Fig. 1. Solar collector area installed per annum (\(\Sigma A_{SC}\)) in Taiwan.](image-url)

Table 1

<table>
<thead>
<tr>
<th>Funding agency</th>
<th>Period</th>
<th>Collector-area-based subsidies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bureau of Energy, MOEA (BEMOEA)</td>
<td>1986.01–1992.06</td>
<td>2000 NTD/m², 1000 NTD/m² from 1990 to 1991</td>
</tr>
<tr>
<td>BEMOEA</td>
<td>2000.07–2008.12</td>
<td>1500 NTD/m²</td>
</tr>
<tr>
<td>BEMOEA</td>
<td>2009.01–2015.12</td>
<td>2250 NTD/m²</td>
</tr>
<tr>
<td>Government of Kinmen county</td>
<td>2008.03–2017.12</td>
<td>3000 NTD/m² (2008.03–2008.12); 4500 NTD/m² (2009.01–2017.12) Subsidizing up to (A_{SC} = 6) m² after April 1, 2010</td>
</tr>
<tr>
<td>Government of Chiayi county</td>
<td>2011.01–2011.12</td>
<td>2250 NTD/m²</td>
</tr>
<tr>
<td>Government of Yulin county</td>
<td>2011.01–2015.12</td>
<td>2250 NTD/m²</td>
</tr>
<tr>
<td>Government of Penghu county</td>
<td>2012.01–2018.12</td>
<td>3000 NTD/m²</td>
</tr>
<tr>
<td>Government of Lienchiang county</td>
<td>2015.01–2018.12</td>
<td>4500 NTD/m²</td>
</tr>
<tr>
<td>Government of Taichung city</td>
<td>2015.01–2015.12</td>
<td>2250 NTD/m²</td>
</tr>
</tbody>
</table>

1 USD = 33 NTD
In a PV/T module with a liquid collector, a traditional flat plate collector containing heat-transport fluid is incorporated into the bottom of the PV module. Fluid flows through the pipes of the collector to transfer heat from the PV module. In a PV/T module with an air collector, the air collector is attached to the bottom of the PV module, and the system cost is lower than that of a PV/T module with a liquid collector. A ventilated PV module with a heat recovery system can be combined with a building-integrated PV module. In a sunlight-concentrating PV/T module, optical lenses are used to concentrate sunlight onto a small area to reduce heat loss, and the temperature in such a module can generally reach 120 °C or higher. Although the global market for PV/T modules remains small, such modules demonstrate considerable market potential because of their overall efficiency. There are several commercial products available in the market.

The general public’s knowledge of SWHs is mostly confined to domestic use in cleaning and washing. However, the ECO-HEATCOOL project reported that 30% of the heating demand in European industries was lower than 100 °C and 57% was lower than 400 °C (Ecoheatcool-WP1, 2005). Various industries (such as the food, wine and beverage, transportation, mechanical, textile, and pulp and paper industries, which have a thermal energy demand of lower than 250 °C) constitute 60% of the entire thermal energy demand (Karagiorgas et al., 2001; Mekhilef, et al., 2011 Lauterbach, et al., 2012). However, integrating SWHs into the operation of existing heating equipment or heat recovery systems must be considered.

## 3. Results and discussion

### 3.1 Building integrated solar thermal, BIST

Architectural type of buildings limits SWHs installation. In Taiwan, domestic SWHs are mostly installed on the flat roof of townhouses. Although the number of households in northern Taiwan (i.e., Taipei City, New Taipei City, and Keelung City) is one-third of the total number of households in Taiwan, the number of SWHs in this region is only 0.89% of the total number of systems installed; this is because the building patterns in this region are mostly apartments or high-rise buildings (Chang et al., 2013). Therefore, how to promote the installation of SWHs in metropolitan cites is a crucial topic. Currently, new buildings established annually constitute approximately 3% of the total building structures, among which 30% are ideal for installing SWHs (Chang et al., 2008). Apart from product quality and selling price, a key factor for promoting BIST systems is encouraging the architecture and construction industries to adopt such modules. Furthermore, to ensure the efficient installation and integration of solar collectors into buildings, wind-resistant structural designs in addition to water-proofing, drainage, and leak-resistance architecture must be considered.

Currently, SWHs in Taiwan are installed using the conventional rack-mounted system, and solar collectors are oriented at 15–30° to achieve optimal thermal efficiency. However, because Taiwan is subjected to three to four typhoons on average every year, SWHs must possess sufficient wind-resistance capability to prevent them from being easily damaged (Chung et al., 2011).

Regarding the exterior of buildings, solar collectors must be integrated with the building design such that the thermal efficiency is not affected (Probst and Roeker 2007; Maurer et al., 2013). Some BIST systems (for various purposes such as sloping roof, parapet, railings, and rain shelter) have been installed in Taiwan. In the future, new solar collectors for BIST systems should be developed and introduced into the market after testing and demonstration. For subsidy policies, the subsidy for SWHs with glazed flat-plate and evacuated-tube solar collectors was NTS 2250/m² (1USD ≈ 33NT$); the subsidy for SWHs with unglazed flat-plate type solar collectors was NTS1500/m² (Chang et al., 2011). For BIST systems, the current subsidy model can be maintained to promote the use of solar thermal energy in metropolitan areas.

### 3.2 Photovoltaic/thermal system (PV/T)

PV/T has been a focus for R&D for two decades. According to the “Solar Thermal Action Plan for Europe” of the European Solar Thermal Industry Federation (ESTIF, 2007), the largest market potential of PV/T systems lies in the residential domain (approximately 90% of the market share). Currently, such systems mainly provide heated water and a specific portion of electricity to townhouses. Future targets include the application of such systems to commercial domains. Roof windows and outer walls are generally the building surfaces that receive the most sunlight. Therefore, solar PV modules can supply a certain portion of electricity to a green building and solar thermal energy can be harnessed to provide hot water. In Taiwan, the “Million Rooftop PVs Project” was initiated by the BEMOEA in 2011. The total capacity installed for solar PV is 0.62 million kW in 2014. Feed-in tariffs (FITs), ranging from 5.23 NTD/kWh to 7.16 NTD/kWh, were offered. For PV/T products, there are only two SWH manufacturers and one manufacturer specializing in copper indium gallium selenide solar cell modules involved. Nevertheless, future PV/T module development will require establishing integrated modules, computer-aided fluid flow simulation and analysis approaches, and structural design techniques for developing systems with high heat conductivity, high voltage resistance, and weather resistance. Such modules should be promoted by convening solar thermal/photo-voltaic industry symposiums to compile industry demands and devise plans for product promotion according to industrial standards (such as system design, installation and inspection regulations, and training and counseling on system installation skills). Incentives for energy savings, FITs, and thermal quantity grants should also be considered (Liou, 2010; Wang and Cheng, 2012). Furthermore, international PV/T module testing standards can be referenced for establishing a national testing standard as well as a standard testing laboratory to facilitate product development and testing and provide verification services. The Taiwan government should provide grants for establishing PV/T demonstration systems and formulate a dual subsidy program for heated water and electricity. Moreover, monitoring devices can be employed to conduct field measurements to examine the actual operability and economic efficiency of developed modules; such monitoring data can also serve as a reference in promoting PV/T systems.

### 3.3 Solar thermal for industrial heating process

In Taiwan, 93% of SWHs were installed in the domestic sector (Lin et al., 2012; Chang et al., 2013). Industrial heat processes represent an area for solar thermal applications. During the last two decades, several industries have effectively employed solar thermal energy. For instance, several meat markets apply SWHs for preheating water used for scalding processes after slaughter and subsequent cleaning (Liu et al., 2015). Manufacturers of plate-fin heat exchangers also use SWHs for preheating to subject heat exchangers to acid cleaning. SWHs are also employed in beverage production. In addition, although the demand for greenhouses in Taiwan is limited, SWHs are employed in orchid cultivation for heating the water in pipelines in greenhouses to maintain a steady temperature (28 °C) for cultivation. Therefore, solar thermal applications have high potential for development. Furthermore, because nonresidential SWHs are mostly used in areas of high...
thermal demand, combining SWHs with other energy-saving products is another key issue. For instance, heat pumps are commonly integrated with SWHs and demonstrate a coefficient of performance exceeding 3.0 (Panaras et al., 2013; Dai et al., 2015).

In Taiwan, the performance of solar thermal products is inspected based on CNS 15165 (solar collectors) and CNS 12558-B7277 (SWHs). In addition to the thermal efficiency, elements such as solar radiation, installation angle, system design, and hot water consumption affect the real thermal output of SWHs. Therefore, to develop the industrial and commercial application of SWHs, the government can devise grants for nonresidential SWHs. First, thermal output monitoring devices can be installed to enable manufacturers to determine the actual energy savings of SWHs and consequently encourage them to improve their system designs. Users can also observe the status of SWHs and execute regular maintenance. Second, thermal output monitoring devices must be implemented to enable inspectors to determine whether the products meet relevant standards. Devising a set of standard installation procedures for measuring the thermal output of various SWHs is also imperative (Crowther et al., 2010). Moreover, because thermal output measurement is time consuming, maintaining stability during lengthy operations in outdoor environments is critical. Furthermore, current Taiwan-government-implemented FITs for PV systems can be referenced for devising thermal output subsidies. Subsidies for SWHs can be granted according to the actual consumption of solar thermal energy.

4. Conclusions and policy implications

Because of concerns such as climate change and environmental protection, energy savings and reduction of carbon emissions have been emphasized worldwide. To promote solar thermal applications, subsidies of any form can be provided to lower the acquisition cost. Since 2000, Taiwan government’s subsidization toward solar thermal systems has led to the effective increase in the total installation area of solar collectors, but long-term subsidization has progressively lost effectiveness and is distorting the free market. In Taiwan, future projects associated with solar thermal application, should include (1) analyzing the effectiveness of BIST systems and establishing demonstration systems; (2) conducting research on PV/T technology, promoting related products in addition to establishing regulations for product inspection; (3) promoting the use of nonresidential SWHs and enhancing the efficiency of such systems; and (4) implementing research and development on thermal output monitoring instrumentation and building demonstration systems. The application of solar thermal systems is expected to increase immensely. In addition to partly replacing existing fossil energy sources, solar thermal systems can facilitate achieving the target of the Greenhouse Gas Emission Reduction and Management Act. Regarding government policies, a subsidy model for demonstration systems must be devised first. For promotion of solar thermal energy, the current purchased-based subsidy model is suitable only for BIST systems in the domestic sector. For the application of PV/T and industrial heating systems, a new subsidy policy that is based on system thermal output should be implemented. Also, a dual subsidy program (heated water and electricity) for PV/T systems is required.

Acknowledgements

This work was supported by the Bureau of Energy, Ministry of Economic Affairs (103-D0303), Taiwan, Republic of China. The authors declare no conflict of interest.

References


