Effectiveness and weaknesses of supporting policies for solar thermal systems—A case-study

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1. Introduction

The world market for solar thermal systems has been growing continuously since the beginning of the 1990s. According to a recent study of IEA (2013) on solar thermal market conducted for 56 countries all over the world, an installed capacity of 234.6 GW_{th} corresponding to a total of 335.1 million m^2 of collector area was in operation by the end of 2011. The installed capacity in these countries represents more than 95% of the solar thermal market worldwide. The vast majority of the total capacity in operation was installed in China (152.2 GW_{th}) and Europe (39.3 GW_{th}), which together accounted for 81.6% of the total installed.

The European Union pledged to achieve by 2020 a 20% share of renewable sources in final energy consumption and the same share as reduction of final uses. To achieve these goals, the solar thermal sector should provide an important contribution, since the demand for heating and cooling accounts for 49% of the total energy demand in Europe. Within the heating and cooling sector, solar thermal energy will play a vital role. To date, it has only covered a minor share of the heating demand in Europe, although it has the greatest potential of all renewable energies for heating and cooling.

At the European level, in spite of the decrease recorded over the last four years, the annual market size for solar thermal systems has doubled over the past decade at an average annual growth rate of 10% (ESTIF, 2013). The outlook remains uncertain, but it is expected that the main markets could be negatively affected by the lack of government incentives programs and stagnation in the construction industry resulting from the global financial crisis. Pos-itive and opposite effects should be generated by the RES Directive (2009/28/EC), that should contrast the stagnation by introducing incentives for heat production from renewable sources (NREAP, 2009).

The development of the solar thermal market over the last decade shows its strong dependency on external factors, e.g. fossil fuel energy prices, new evolving heating technologies, supporting programs etc. This translated into great uncertainties in the market forecasts and reinforces the need for a strong political support to accelerate the market uptake of solar thermal (ST). One of the barriers for the diffusion of ST technology could be attributed to the high cost of ST systems. Solar thermal heat is often not yet competitive, but the potential of cost reduction, which can be achieved through R&D support, is still vast and the market develops well. As evidenced, since 1995 solar thermal collector production costs

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have been cut by nearly 50%, which corresponds to a learning factor of 23% achieved over the past 15 years (ESTIF, 2012).

In the past, several European countries adopted the policy to support ST technology by providing different financial incentives to stimulate the market (Beerepoot, 2007; ESTIF, 2006; Roulleau & Lloyd, 2008; Valentini & Pistochini, 2011). The overview on these energy policies is discussed in the following section. Currently, financial incentives for solar thermal energy, together with other systems for generating heat from renewable sources, are planned or under study at national level (D.M. 28/12/2012; DECC, 2001).

As an effective example of such energy policy in recent years, the Italian Ministry of the Environment, in collaboration with Lombardy Region (northern Italy), has developed several measures for energy efficiency and local renewable integration in the regional territory, within the so-called Framework Program Agreement on Energy and Environment. Public support has consisted in the provi-sion of grants to finance companies and private entities, on the basis of a public selection. Among various measures, one is related to the diffusion of solar thermal (ST) systems in the built environment. The incentives were provided within different calls: most of the sys-tems funded are SWH, and a few belong to advanced technologies related to space heating and cooling applications. This paper aims to evaluate the effectiveness of supporting strategies for SWH through a comprehensive assessment on the Lombardy Region case-study; to that end, representative energetic, environmental and economic indicators were calculated and ana-lyzed.

2. Financial incentive schemes for solar thermal technologies in the European countries

Solar thermal technology has been promoted by different kinds of financial incentives (FI) in a number of European countries, regions and local communities. Financial incentives include any public policy providing a financial advantage for solar thermal systems. In Europe, in the past, two kind of main mechanisms for FI have been used: Direct grants/subsidies and Tax credits/reductions.

Direct subsidy is the most common type of policy to promote renewable energies. Solar water heaters have been subsidized in many regions and countries such as Austria, Germany, Sweden, Netherlands, Italy, Greece, however, the way the subsidy is granted can lead to different results. In most cases, the subsidy is related either to the collector area, or to the system performance.

In addition to direct subsidies, some governments, including France, Greece and Italy, used and currently use tax cred-its/deduction as a financial incentive. In the tax credit scheme, a fraction of the capital cost of the SWH system is deducted from the amount of tax that the consumer had to pay. As for tax cred-its, tax deductions are related to the customer's income tax. By off-setting investment costs against taxable income, the customer could reduce investments costs. In Greece, such a policy tool has been used in the past and is currently effective in Italy.

Some examples of such financial incentives in European countries are described below.

Germany has provided grants to solar water heating systems since 1995, first by a '100-million-program' followed in 1999 by Market Stimulation Program (MSP), which remained effective until 2009. The German MSP was extremely successful just up to 2001, because the volatile promotion rate due to the interruptions and regular corrections in the program led to strong fluctuation in market adoption. Despite the obvious lack of stability, the MSP was successful in terms of overall market development.

Austria sponsored solar thermal systems for almost 30 years. High-level grants and the confidence in efficient solar water heaters, enforced by long-duration policy, have enabled the success of solar thermal energy in Austria.

In Sweden (Roulleau & Lloyd, 2008), a subsidy scheme was launched in 1992, but then abandoned in 1997 and a new subsidy was introduced in 2000. The Swedish program led to an increase in the solar collector area installed during the years 2001–2005, however also led to an increased price of the solar energy sys-tems installed. This could be explained by the fact that during the financial incentive regime the demand for solar thermal sys-tems increased rapidly, but the supply did not in the same way, and therefore the system costs increased, experiencing a so-called Renewables Incentive Paradoxical-Effect (RIPE). The results of the solar subsidy policy in Sweden, however, appeared to be disappointing in terms of penetration, but this should be viewed in light of Sweden having a very strong market for heat pumps and the availability of solar radiation being one of the lowest in Europe.

In the Netherlands, the government has been implementing subsidy schemes since 1988. As an effect, between 1994 and 2001 the solar collectors area installed annually in the Netherlands increased steadily. By 2003 and the end of the subsidy scheme, however, the annual additional installed solar collector area started to decrease, suggesting that the installation rate was tied to the subsidies. In fact the installation of SWH in existing buildings nearly stopped, but the new-built sector has, however, remained active because of the increasingly tight energy efficiency requirements for new buildings. In fact, another study (Beerepoot, 2007) concluded that the incentive from energy performance stan-dards in the Netherlands appeared to be too low to promote the use of solar thermal systems, and that energy performance standards need to be more severe in order to stimulate such use.

The first French incentive policy "plan soleil" was launched in 1999 and remained effective for 9 years, until 2008. The policy evolved considerably during the first 7 years. Initially, the user of a solar water heater benefited from a subsidy as well as a reduction in VAT, then replaced by a progressively increasing tax credit. Buyers, however, benefited from the tax credit after 1 year of the purchase of the system, which may have had an adverse impact on the effec-tiveness of the scheme. By 2006, France had the most subsidized solar hot water market in Europe; as a consequence, France thus had the fastest growth of SWH sales in Europe. However, while deploy-ment grew, the costs of the SWH increased between 2000 and 2006. A RIPE effect, as in the case of Sweden, could partly explain this increase in cost, but the perverse effect of a tax credit scheme may also be the answer.

In 1970, Greece started an incentive program of high amount of tax deduction on solar thermal systems, which led to reaching the market for SWH in 2002 at a critical size and being capable of self-supporting. The tax deduction program in Greece was judged to be very successful, at least during the first years. However, the policy had an important equity issue; people who paid the highest amount of taxes (the richest part of the population) obtained the maximum cost reduction.

In Italy, in the past, solar thermal technologies were supported through subsidy incentive schemes at regional levels across the Country (ESTIF, 2006). The current scheme, 55% tax deductions, in force since 2007, represents the most generous system of incentives ever established by the Government to promote energy efficiency and thus solar thermal systems in the Italian real estate context (Valentini & Pistochini, 2011). The effect of this incentive scheme is evident: during these years the Italian market for solar thermal systems is growing continuously and has consolidated its second position in Europe, after Germany (ESTIF, 2013).

As described above, in many cases the financial incentives for supporting solar thermal technology worked well and produced a significant effect on market development. In other cases, finan-cial incentives were not as effective, and, in the worst cases, sometimes had counter-productive effects. For example, in the case of Germany and Austria, the financial incentive policies have been successful, when the level of subsidy is significant compared to the total cost of the systems and the duration of the scheme is long enough to provide confidence to both the consumer and the solar industry. However, in the case of Sweden and France, a short-term subsidy scheme led to a so-called renewable incentive paradoxical effect (RIPE) thereby increasing system costs. The experiences also suggest subsidy policies conducive to expanding system installations, but deployment alone does not indicate either whether the systems are working well or if they are reducing the overall national energy consumption.

Financial incentives have shown to be a very effective tool to stimulate growth in renewable energies and solar thermal markets, but they are typically not very effective if applied without suitable flanking measures linked to the specific design and implementation issues, e.g. limited public financial resources, lack of awareness from potential purchasers, lengthy or difficult planning procedures, lack of understanding and thus motivation by key influencing professional groups and lack of expertise sharing between local authorities (Argyriou, Fleming, & Wright, 2012).

3. Analysis of a case-study

In this work a significant and long-lasting supporting-policy Program on solar thermal systems was chosen as a case-study. In detail, from 2002 to 2009 the Italian Ministry of the Environment, in collaboration with Lombardy Region, developed a series of specific measures for the diffusion of SWH systems in the built environment, within the so-called Framework Program Agreement on Energy and Environment promoted at national level. Lombardy, located in northern Italy, is characterized by a sub-continental temperate climate and an average yearly value of irradiation on horizontal plane equal to 1250 kWh/m^2, thus being representative of a central-southern Europe climatic context. Moreover, the chosen case-study is particularly relevant, since Lombardy is the Italian region with the highest gross domestic product, considerable population and building density and was interested by these enduring subsidies to SWH. In detail, public support consisted in the provision of grants to finance companies and private entities on the basis of a public selection and incentives were provided within different calls, characterized by different levels of funding; in some cases the grant was calculated proportionally to the expected yearly thermal energy production of the plant, with a maximum quota equal to 25% of the system total cost, and in other cases directly as a fraction of the system cost, equal to 50%, without a limit on the subsidy amount.

Since the Politecnico di Milano was commissioned to perform the monitoring of the results of such Program, it was possible to carry out the analysis on a large sample of data about SWH systems, covering a total of 1210 systems pertaining installations on different types of users, corresponding to a total area of solar collectors approximately equal to 16,500 m^2 and to an overall cost equal to around € 16,700,000. The specific breakdowns of the interventions, by system type and destination, are shown in Fig. 1.

As it can be seen from the above graph, the majority of installed systems, with a share of almost 79.3%, is aimed at the production of domestic hot water (DHW), followed by a 10.4% of installations aimed both at DHW production and space heating. Moreover, most of the analyzed systems belong to the residential sector, which represents the destination of approximately 80% of the whole dataset and of 90% of plants for DWH.

For the purpose of this analysis, all necessary information was obtained by the available technical and economic data collected during the monitoring campaign, according to the following list:

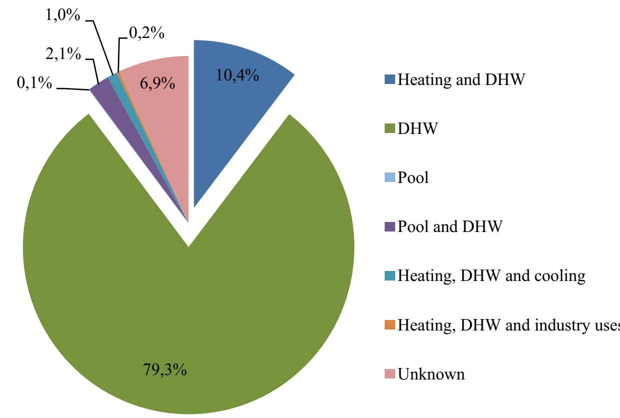

Fig. 1. SWH systems types.

- *Geographical data:* geographical information of the installation site;
- *Technical data*: system type (heating, DHW, etc.), class of use (residential, business etc.), number and type of collectors (flat plate, evacuated tubes, unglazed), performance parameters of the collectors ($F'(\tau\alpha)$ and $F'U_L$), tilt and azimuth of the collectors, heat demand by users connected to the plant, number of users served by the plant and expected yearly thermal energy production of the plant;
- *Economic data*: starting budget for the plant installation, final total turnkey cost paid for the SWH system and subsidy received by owners from Lombardy Region for the construction of each plant.

It is worth noting that the expected yearly thermal energy production by the system was calculated and certified by each SWH system's designer and checked by Lombardy Region's technicians. However, in this research all data on energy production was verified through the calculation method provided by the national standard, UNI/TS 11300-4 norm (2012) and just 3% of outliers was identified and removed from the dataset. On average, the validated SWH systems were characterized by a mean specific expected thermal energy production equal to approximately 760 kWh$_t$/m^2 year and an annual average conversion efficiency of around 50%.

Subsequently, by analyzing and processing above-listed information, it was possible to obtain energy, economic and environmental indicators in order to carry out a comprehensive evaluation of the plants performances and to analyze the effectiveness of the contributions granted. Such indicators are described in Table 1.

All proposed indicators were determined as described below for each SWH plant analyzed but, in order to carry out a comprehensive and representative assessment on the whole dataset, the respective weighted mean values were subsequently calculated for each year examined.

3.1. *Specific turnkey cost*

The specific turnkey cost is calculated as the ratio of the total amount paid for the installation of a SWH plant and the same plant total collectors' surface, according to the following formula:

$$C_{\mathrm{inst,S}} = \frac{C_{\mathrm{inst,T}}}{A} \tag{1}$$

where:

$C_{\mathrm{inst,S}}$ is the specific cost the SWH system, in €/m^2; $C_{\mathrm{inst,T}}$ is the total turnkey installation cost the SWH system, in €; A is the total surface of plant solar collectors, in m^2.

Subsidy per unit area of solar collectors

Table 1
Calculated energy, environmental and economic indicators.

Calculated indicator	Description
1) Specific turnkey cost	The ratio between the turnkey cost of a specific plant and the total area of installed collectors of the same plant, expressed in €/m^2.
2) Subsidy per unit area of solar collectors	The ratio between the financed subsidy for a specific plant and the total area of installed collectors of the same plant, expressed in €/m^2.
3) Cost of avoided CO_2	This value, expressed in €/tCO_2, represents the ratio of the total subsidy actually paid to the beneficiary, and the amount of avoided CO_2 emissions during the useful life of the plant, assumed equal to 20 years. It represents the cost for society of each avoided ton of CO_2.
4) Mean cost of substituted conventional thermal energy from traditional water heating systems	It represents the average cost in the analyzed context of conventional thermal energy produced with traditional water heating systems which can be integrated by SWH systems, expressed in €/kWh$_t$.
5) Levelized cost of thermal energy from SWH	The ratio of the discounted total cost for a specific plant (construction, operation and maintenance) and the net energy production during its useful life, assumed equal to 20 years, expressed in €/kWh$_t$. It is calculated with and without subsidy.

The subsidy per unit area of solar collectors is determined as the ratio of the total amount of incentive received by public funding for a certain SWH system and the same plant total collectors' surface, according to the following formula:

$$S_S = \frac{S_T}{A} \tag{2}$$

where:

S_S is the subsidy per unit area of solar collectors, in €/m^2; S_T is the total amount of subsidy received by public funding for a certain SWH system, in €; A is the total surface of plant solar collectors, in m^2.

3.2. Cost of avoided CO_2

As stated before, the cost of avoided CO_2 can be calculated with the following relation:

$$C_{CO_2} = \frac{S_T}{E_{CO_2,\mathrm{ul}}} = \frac{S_T}{TE_{\mathrm{ul}} \times EF_{\mathrm{wa}}} \tag{3}$$

where:

S_T is the total amount of incentive received by public funding for a certain SWH system, in €; $E_{CO_2,\mathrm{ul}}$ is the total amount of CO_2 emission avoided during the same plant's useful life, in kg;

TE_{ul} is the total amount of thermal energy that can be produced by the SWH system during its useful life, in kWh$_t$, which is equal to the plant yearly thermal energy production multiplied by the system useful life, equal to 20 years (UNI EN 15459, 2008).

EF_{wa} is the mean CO_2 emission factor for conventional thermal energy in the context analyzed [kgCO_2/kWh$_t$], calculated according to the following formula:

$$EF_{\mathrm{wa}} = \frac{EF_e}{\eta_e} \times p_e + \frac{EF_o}{\eta_c} \times p_o + \frac{EF_{\mathrm{ng}}}{\eta_c} \times p_{\mathrm{ng}} + \frac{EF_{\mathrm{lpg}}}{\eta_c} \times p_{\mathrm{lpg}} \tag{4}$$

where:

EF_{wa} is the mean CO_2 emission factor for thermal energy [kgCO_2/kWh$_t$]; EF_e is the emission factor for electricity [kgCO_2/kWh$_e$]; η_e is the average efficiency of plants with electric water heaters (generation, distribution, control and emission), equal to 90% (UNI TS 11300-2, 2008); p_e is the share of electric heaters for DHW production [%]; EF_o is the emission factor for heating oil used in combustion boilers [kgCO_2/kWh$_t$]; η_c is the average efficiency of plants with combustion boilers (generation, distribution, control and emission), equal to 70% (UNI TS 11300-2, 2008); p_o is the share of combustion systems for DHW production fueled with heating oil [%]; EF_{ng} is the emission factor for natural gas used in combustion boilers [kgCO_2/kWh$_t$]; p_{ng} is the share of combustion systems for DHW production fueled with natural gas [%]; EF_{lpg} is the emission factor for liquid petrol gas used in combustion boilers [kgCO_2/kWh$_t$]; p_{lpg} is the share of combustion systems for DHW production fueled with liquid petrol gas [%].

Table 2
CO_2 emission factors used in the calculations.

	EF [kgCO_2/kWh]
Electricity	0.398
Natural gas boiler	0.199
Heating oil boiler	0.264
Liquid petrol gas boiler	0.232

The emission factors used as a reference for the Regional context are summarized in Table 2 (FinLombarda, 2013).

The calculation of specific shares of electric heaters and combustion systems with different fuels was carried out considering the average breakdown of the fuels used and the prevailing types of plants in Lombardy. The basic hypothesis is that the SWH systems installation followed proportionally the same distribution as the conventional water heating systems existing in the context analyzed; such analysis was necessary because specific information about water heating technologies and fuels related to the users who installed the SWH systems were not always available.

Therefore ISTAT data (2001) relative to the diffusion of domestic systems for heating/DHW production and sales figures of heating fuels in the Lombardy Region (ENEA, 2008) were analyzed; the various shares were determined as reported in Table 3.

According to the proposed methodology, the calculated weighted mean CO_2 emission factor for conventional thermal energy is thus 0.315 kgCO_2/kWh$_t$.

3.3. Mean cost of thermal energy from traditional water heating systems

The mean cost of conventional thermal energy that is delivered by existing water heating systems, expressed in €/kWh$_t$, varies yearly according to average fuels and electricity prices in the analyzed context and is calculated considering the same share of plant types/fuels described above, according to the following relation.

$$C_{\mathrm{E,wa,i}} = \frac{C_{E,e,i}}{\eta_e} \times p_e + \frac{C_{\mathrm{E,ng,i}}}{\eta_c} \times p_{\mathrm{ng}} + \frac{C_{\mathrm{E,o,i}}}{\eta_c} \times p_o + \frac{C_{\mathrm{E,lpg,i}}}{\eta_c} \times p_{\mathrm{lpg}} \tag{5}$$

where:

$C_{\mathrm{E,wa,i}}$ is the mean cost of thermal energy in a certain year [€/kWh$_t$]; $C_{\mathrm{E,e,i}}$ is the average price of electricity for civil uses in a certain year [€/kWh$_e$]; η_e is the average efficiency of plants with electric water heaters (generation, distribution, control and emission), equal to 90% (UNI TS 11300-2, 2008); p_e is the share of electric heaters for DHW production [%].

Table 3
Shares of electric heaters and combustion systems.

Types of water heaters	p [%]
Electric heaters	9.6
Combustion systems for DHW production fueled with natural gas	70.3
Combustion systems for DHW production fueled with heating oil	12.4
Combustion systems for DHW production fueled with liquid petrol gas	7.7

Table 4
Mean costs of conventional thermal energy in a reference year.

Reference year	Mean cost ($C_{E,wa,i}$) [€/kWh$_t$]
2002	0.082
2003	0.087
2004	0.090
2005	0.098
2006	0.106
2007	0.112
2008	0.121
2009	0.125

$C_{E,ng,i}$ is the average price of natural gas for civil uses in a certain year [€/kWh]; η_c is the average efficiency of plants with combustion boilers (generation, distribution, control and emission), equal to 70% (UNI TS 11300-2, 2008); p_{ng} is the share of combustion systems for DHW production fueled with natural gas [%].

$C_{E,o,i}$ is the average price of heating oil for civil uses in a certain year [€/kWh]; p_o is the share of combustion systems for DHW production fueled with heating oil [%].

$C_{E,lpg,i}$ is the average price of liquid petrol gas for civil uses in a certain year [€/kWh]; p_{lpg} is the share of combustion systems for DHW production fueled with liquid petrol gas [%].

The reference prices are those recorded yearly by AEEG (Italian Authority for Electricity and Gas) (2012) for natural gas and electricity and by MSE (Ministry of Economic Development) (2012) for LPG and heating oil. Obtained results are summarized in Table 4.

3.4. Levelized cost of thermal energy from SWH

The Levelized Cost Of Energy (LCOE) is defined as the sum of all costs incurred over the lifetime of a given generating technology divided by the energy produced (Short, Packey, & Holt, 1995). Typically, such value is calculated for electricity generators, but it can be also applied to thermal energy generators, according to the following formula.

$$\mathrm{LCOE} = \frac{\sum_{t=1}^{n} (C_{\mathrm{inst,T}} + C_{\mathrm{O\&M}}/(1+r)^t)}{\sum_{t=1}^{n} TE_{\mathrm{ul}}/(1+r)^t} \tag{6}$$

where:

LCOE is the average lifetime levelized solar thermal energy cost [€/kWh$_t$]; $C_{inst,T}$ is the total turnkey installation cost of the SWH system, in €; $C_{O\&M}$ are the operating and maintenance expenditures in the year t [€], calculated as follows:

- yearly maintenance costs equal to 2% of turnkey cost (RHC-Platform, 2013);
- yearly operating cost equal to the cost of the electricity due to circulation pump, which is determined according to the UNI/TS 11300-4 norm;

TE_{ul} is the total amount of thermal energy that can be produced by the SWH during its useful life, in kWh$_t$, which is equal to the plant yearly thermal energy production multiplied by the system useful life, equal to 20 years.

r is the discount rate, assumed equal to 3% (RHC-Platform, 2013);

n is the working-life of the system, equal to 20 years (UNI EN 15459, 2008);

4. Reference data

Before examining the numeric values of the proposed indicators referred to in the case-study analyzed, in order to compare and evaluate them, it is worth getting some reference data related to the European context, as described hereafter.

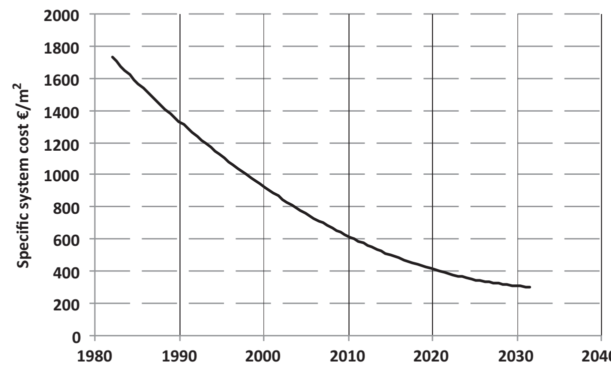

Fig. 2. Development of specific system costs for small solar thermal systems (forced circulation) in central Europe.
Adapted from ESTIF (2009).

4.1. Reference turnkey cost of SWH systems

The costs for SWH systems differ considerably and depend on the system configuration, local market and conventional energy cost. Over the last decade, based on previous experiences with the design and operativeness of SWH systems, it has been well evidenced that the learning took place, and as a result, investment cost reductions of around 20% have been observed for each 50% increase in the total installed capacity of solar water heaters (Fig. 2). Furthermore, the cost reduction potential can be seen in the increase of productivity through the mass production of standardized systems, which reduce the need for on-site installation and maintenance works (ESTIF, 2009; RHC-Platform, 2013).

An average specific turnkey cost, at the European level, for small solar thermal systems with forced circulation can thus be assumed to be between approximately 900 €/m^2 in the early 2000s and 600 €/m^2 in 2010.

4.2. Cost of thermal energy from SWH systems

The cost of thermal energy from SWH systems obviously depends on both the system turnkey cost and the average thermal energy production, which in turn is a function of the specific climatic context; for this reason, values related to different climatic conditions and system technologies must be carefully compared. However, from the literature it is possible to state that the costs of thermal energy, produced by SWH plants installed in central and southern EU, range approximately between 0.05 and 0.16 €/kWh$_t$ depending on the boundary conditions (ESTIF, 2009).

4.3. Reference cost of avoided CO_2

To assess the actual economic value of CO_2 emission is not a simple task because, actually, there is not a precise and unambiguous estimation of this value. In particular, there are two main references for monetizing a ton of CO_2: the first is its market value, resulting from the quotation of the Emission Trading System (ETS), while the second is the calculation of the Social Cost of Carbon (SCC).

Deepening the issue, the average market quotation on the European ETS (EU ETS, 2014), launched in 2005, is based on the "cap-and-trade" system, meaning that an overall limit, or "cap", is set on the total amount of emissions and then such quantity is allocated or sold on the stock market to companies in the form of emissions permits, allowing the buyer to pay a charge for polluting to the seller, who is rewarded for having reduced emissions. Since it is a stock market quotation, the European CO_2 market price experienced high fluctuations from 2005 to present, raising 30 €/t in 2006 and decreasing to almost 0 €/t recently, with an average value equal

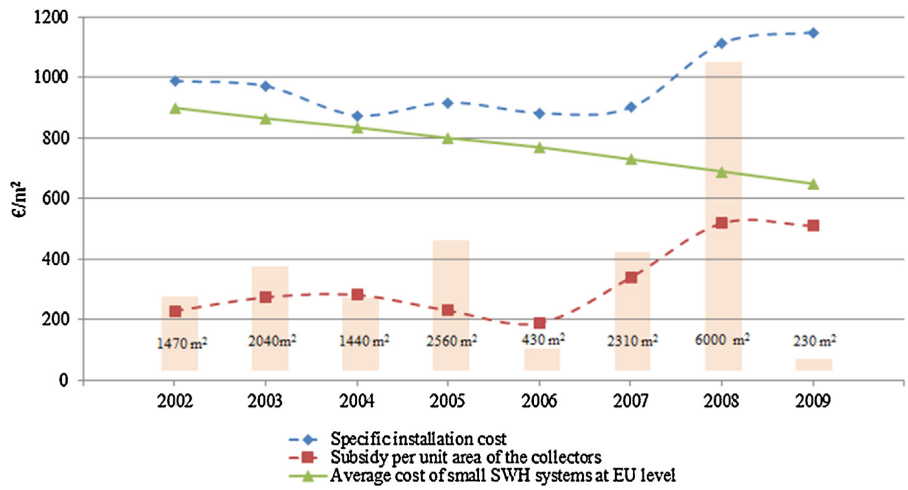

Fig. 3. Specific installation turnkey cost (blue), subsidy per unit area of solar collectors (red) and trend of the average specific system cost for small solar thermal systems (forced circulation) in central Europe (green), along with the total installed SWH surface per year (bar chart with labels indicating specific surfaces).

to approximately 15 €/t. Such movements and the implied volatility raise questions about the effectiveness of this trading system (Ellerman & Joskow, 2008), insomuch than a major revision was approved in 2009 in order to consolidate it. On the other hand, the Social Cost of Carbon is meant to be a comprehensive estimate of future effects of climate change, since it represents the monetized value of the marginal benefit of reducing one metric ton of CO_2. In detail, it is equal to the flow of future damages due to an additional unit of carbon emissions in a particular year, discounted at the present day according to a standard financial calculation (Johnson, Yeh, & Hope, 2013).

A recent US Government research (Interagency Working Group on SCC, 2013) estimated values for such parameter from 2010 to 2050, with a SCC for 2010 equal to [1] 8.25 €/t, 24.75 €/t and 39 €/t, calculated respectively with 5%, 3% and 2.5% discount rates. Different discount rates are chosen because a small variation of this parameter has an high impact on the final cost of CO_2; in fact, calculation models consider that the effects of CO_2 emissions last for hundreds of years, which means that the discounting period is very long; nevertheless, some works, such as the IPCC Fourth Assessment Report (2007) as well as the EPA's technical support document (USEPA, 2008), suggest that, for intergenerational cost-benefits analyses, the discount rates should generally be lower than 3%. For this reason, other estimations of SCC were carried out (Johnson & Hope, 2012) using intergenerational values between 1 and 2% per year and resulted in 200 €/t, and 46 €/t, respectively, per metric ton of CO_2 emitted.

In conclusion, since there is wide disagreement among economists and scientists regarding the "correct" value of the discount rate (Pindyck, 2013), and considering the uncertainty related to the calculation of the comprehensive impact of CO_2, for this work the final economic value of CO_2 was considered between 10 €/t and 200 €/t, rounding values calculated with a discount rate ranging from 5 to 1%.

5. Main results and discussion

The assessment carried out allowed to underline positive global results of various calls for funding set up by Italian Ministry of Environment in collaboration with the Lombardy Region. In particular, the subsidy allowed to boost the market, achieving in 8 years a total of 1210 installed SWH systems, with an overall collectors surface equal to approximately 16,500 m^2; such SWH systems have a positive impact under an environmental point of view, since it was calculated that the total thermal energy from renewable sources amounts to approximately 251,000 MWh_t over their useful life, corresponding to almost 80,000 tons of avoided CO_2.

By analyzing the information collected and the indicators calculated it was possible to obtain a comprehensive scenario on the grant program promoted by the Lombardy Region from 2002 to 2009 on the diffusion of solar thermal systems.

In particular, the trends of the specific turnkey cost and the subsidy per unit area are plotted in Fig. 3 for the entire period of analysis, together with the aforementioned trend of the aver-age specific system cost for small solar thermal systems (forced circulation) in central Europe (ESTIF, 2009).

As it can be observed, the yearly average specific turnkey installation cost for the case-study in 2004 was approximately equal to 875 €/m^2, slightly closer to the average EU value; during the following years, however, the recorded yearly cost increased up to 1.150 €/m^2, deviating a lot from the EU trend.

In addition, it must be noted that in 2008, in correspondence of the highest value of subsidy per unit area, the greatest surface installed was recorded. The surface installed in 2009 is low because the interventions made during such year are just a limited remaining part of the same call of funding started in 2008.

It is possible to state that there is a clear connection between the trend of the specific installation cost and the one of subsidy per unit area: the greater was the subsidy, the higher was the turnkey cost.

It is worth to observe that a considerable number of installations realized between 2007 and 2009 are related to the tertiary sector, carried out by public subjects and medium-sized companies. It is possible that, in some cases, the design complexity of the systems for tertiary sector was greater than that of domestic systems, but also that some unnecessary over-costs could have occurred in the realization process. Conversely, such systems are typically medium to large size installations, where there are often economies of scale that should allow a reduction in final specific costs.

In any case, the recorded average specific turnkey cost during the whole period analyzed did not follow the decreasing trend in solar collectors production cost recorded at the EU level during the same years. This means that, compared to an increase in market volumes, in the case-study analyzed the decrease in SWH turnkey cost did not follow the learning curve trend. It must be specified that, as well as the systems related to tertiary sector, also the specific

[1] An US$-€ exchange rate equal to 0.75 was assumed.

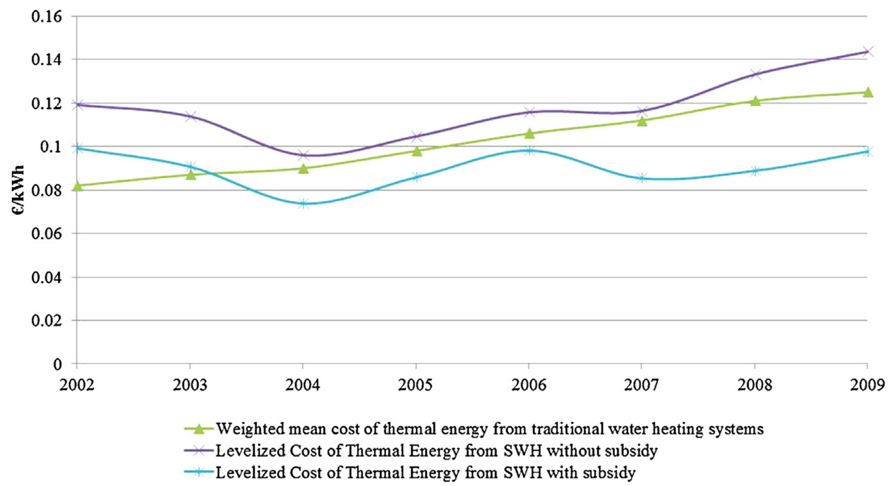

Fig. 4. Weighted mean cost of thermal energy from traditional water heating systems and levelized cost of thermal energy from SWH, with and without subsidy.

cost of residential installations underwent a significant increase in 2008 and 2009.

With regard to the weighted mean cost of thermal energy from traditional water heating systems and the levelized cost of thermal energy produced with SWH, the yearly values related to the entire dataset analyzed are presented in Fig. 4.

The LCOE was calculated both with and without subsidy, to better highlight the effect of the supporting policy on the final cost of thermal energy produced. In particular, it is possible to note that the LCOE without subsidy is always higher than the mean cost of thermal energy from traditional water heating systems: it means that, considering the boundary conditions analyzed, SWH was not competitive with the average of traditional water heating system existing in buildings and a subsidy was needed to boost the market. In this sense, the LCOE with subsidy was always lower than the mean cost of thermal energy from traditional water heating systems, with the exception of the starting years of the Program; it is possible to state that, except for a starting period in the first two years, subsidy made the SWH energy more competitive compared with that produced with traditional water heating systems.

In general, the LCOE without subsidy in 2009 resulted equal to 0.145 €/kWh_t, a medium-high cost if compared with the average LCOE for SWH installed in central and southern EU, which ranges between 0.05 and 0.16 €/kWh_t. This means that the turnkey cost recorded does not fall outside the average values, if compared with the expected energy production levels, but can be definitely considered elevated.

Through the analysis of the aforementioned specific indicators, it was possible to state that, from a cost-optimization point of view, in some cases the amount of subsidy probably adversely influenced the market cost of installed SWH systems without obtaining the expected results; in particular, while the incentive paid for each m^2 of collector should have decreased during the years accord-ing to a projected reduction in specific SWH turnkey cost (ESTIF, 2009), in the case-study analyzed a significant gain in the amount of subsidy was recorded from 2007 to 2009. As described before, during such period the grant provided was determined as a fraction of the system total cost, equal to 50%, without a limit on the specific turnkey cost, while during the previous years the subsidy was calculated proportionally to the expected yearly thermal energy production of the plant. As the system productivity was certified by the designers and checked by Lombardy Region's technicians, an upper threshold on the payable amount per m^2 of installed collectors was inherently set, supporting and easing the system turnkey cost reduction; in addition, when the subsidy was determined on the expected productivity, a limit on the payable grant equal to 25% of turnkey cost was present.

In general, a capital grant scheme based on investment cost like the one analyzed can be less cost-effective than a feed-in-tariff mechanism, since the latter offers a subsidy which is proportional to the actual benefit generated by the plant during a long-term period, while the capital grant is not linked to a real effectiveness of specific measures.

It has been demonstrated that with degressive feed-in tariffs (FIT) that anticipate technical progress, and thus the turnkey-cost reduction, the profits resulting from such technical progress can be shared out more equitably by reducing the total cost borne by the community, while granting subsidies to producers (Menanteau, Finon, & Lamy, 2003).

To finish, the last proposed indicator, that is the cost paid by the public body for each avoided ton of CO_2 emission, is shown in Fig. 5.

The calculated cost of a ton of avoided CO_2 outlined the value of the subsidy per unit area of solar collectors, with a minimum value equal approximately to 42 €/t in 2005 and a peak value of 90 €/t in 2008.

Considering reference values reported above, the avoided CO_2 cost obtained, ranging from 42 to 90 €/t, is clearly higher than the CO_2 market price, but falls within the range of estimated SCC.

6. Lesson learned and conclusions

The assessment carried out allowed to underline the positive global results of various requests for funding set up by Italian Ministry of Environment in collaboration with the Lombardy Region. The results obtained confirm that subsidy programs for renewable energy sources generally have good effects, since they boost the market, increasing the number of installations and the amount of avoided CO_2, according to specific targets at a national or EU level.

However, from a cost-effective point of view, the case-study analyzed demonstrates that capital grants in some cases do not speed-up the expected decrease in the market price of the granted technology, increasing the costs paid by the community for a certain environmental benefit. In particular, a Renewables Incentive Paradoxical-Effect (RIPE) was experienced, according to which the greater is the specific amount of subsidy over the years, the higher is the recorded specific turnkey cost of the specific technology.

In this sense, while digressive feed-in tariffs lead more easily to a self-balancing process on specific installation cost of the granted technology, facilitating the cost-reduction, capital grants based on investment cost have to be specifically planned to get the results expected, according to the actual market costs.

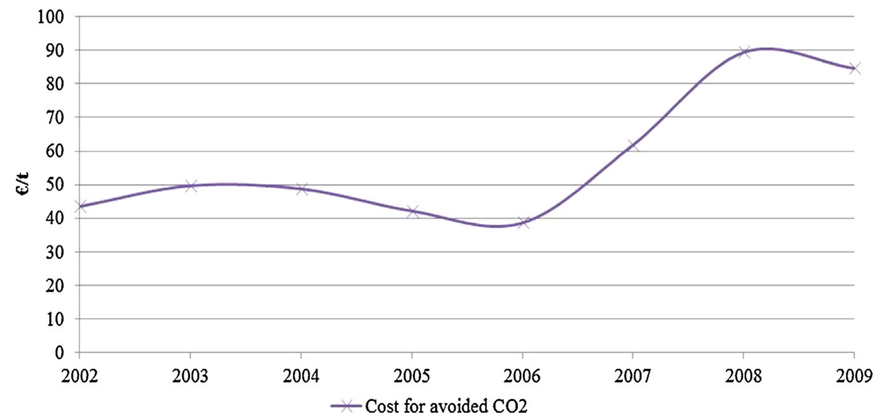

Fig. 5. Cost of avoided CO_2.

However, it must be noted that the application of FIT to SWH systems is not as technically simple as for RES generating electricity, since in the latter case an affordable and reliable metering of the energy produced is feasible, while it is still complex in the former. A specific effort should be carried out in order to develop low-cost and trustworthy technical solutions for such purpose.

In general, the analysis emphasizes also the importance of expertise-sharing between local authorities in the development of sustainable energy and in the policy making process, in order to better outline local actions according to national and international experiences, as already demonstrated by Argyriou et al. (2012).

In conclusion it is possible to state that, especially in case of capital grants, the right amount of subsidies should be carefully determined in advance, according to a mid-term technical development and to cost trends, periodically updated with market surveys on the technology considered. Tailored high-contributions should be specifically focused just on innovative technologies/system configurations, in order to compensate their higher initial costs and promote their evolution and development.

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