Economic Evaluation of Integrated Solar Water Heating System in Different Configurations: A Case Study

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ABSTRACT

Well known economic methods available in literature have been used for the economic evaluation of small-sized integrated solar water heating system (flat plate and evacuated tubular collector) operating under different climatic conditions. Results obtained clearly indicate that the economic evaluations depend not only on the technology and climate but on the specific financial assumptions, as well. Consequent economic evaluations are indicative of the changes that other countries can expect if they can adopt similar incentives.

1. INTRODUCTION

High upfront investment costs and relatively long payback times appear to be the key barriers to the growth of solar thermal systems. A solar thermal converter designed to work at low temperature applications, no doubt, requires minimum operating cost but the fact remains that it still needs high initial capital investment. No device is useful unless it is economically viable and a solar thermal converter is not an exception. A major question regarding solar thermal converters is whether they are viable economically.

Keeping in view the facts stated above, it is necessary that to achieve correct sizing of the system and consequently minimise the overall initial capital investment, both through material and fabrication cost, efforts be made to conduct a detailed economic analysis of the system under investigation. The economic feasibility of these converters depends on the optimisation of the trade-off between high useful energy collected under specified both design and working climatic conditions, attractive financial offers for end-consumers to cope with the investment such like low interest rate, VAT exemption or reduction on solar thermal products and services, facilitated access to credits for investors, economic incentives, easy paying conditions, public support programs, etc. It is in this reference that an attempt has been made to discuss the results obtained from the economic analysis performed on integrated solar water heating system in different configurations (flat plate and an evacuated tubular collector) meant to satisfy hot water requirement of a small-family (4 persons) living at different places with entirely different climatic conditions while taking into consideration the new economic incentives introduced very recently, in Italy.

It is hoped that Italian Environmental Ministry commit to give incentives for the installation of solar thermal systems, in the framework of National Program for the Diffusion of Solar Thermal Technologies, will certainly be helpful to achieve the important objective of the above-mentioned program, (1) to reach 3 million m^2 of solar collector installation by 2010 and (2) to help the development of the solar thermal industry act on demand and supply, and giving a guarantee in product quality at all levels of the product chain.

2. IMPORTANT CONCEPTS OF THE ECONOMIC EVALUATION: A REVIEW [1-7]

The important mathematical definitions used in the economic analysis are discussed below. The present worth V of an amount S to be paid at the end of n years is given by:

$$V = \frac{S}{(1+i)^n} \tag{1}$$

Where i is the market discount rate and the quantity $(1 + i)^n$ is called the capitalisation factor. Present worth of a series of inflating payments S_1, S_2,……S_n made at the end of different annual maturity can be expressed as:

$$V = \frac{S_1}{(1+i)} + \frac{S_2}{(1+i)^2} + ... + \frac{S_n}{(1+i)^n} = \sum_{k=1}^{n} \frac{S_k}{(1+i)^k} \tag{2}$$

In the case of a constant annual sum (= Sc), the above-mentioned equation can be rewritten as:

$$V = S_c\left[\frac{1}{(1+i)} + \frac{1}{(1+i)^2} + ... + \frac{1}{(1+i)^n}\right] = S_c \sum_{k=1}^{n} \frac{1}{(1+i)^k} \tag{3}$$

Here, arithmetical progression in parenthesis is defined as Present Worth Factor $PWF(i,n)$:

$$PWF(i,n) = \begin{cases} \dfrac{1-(1+i)^{-n}}{i} & i \neq 0 \\ n & i = 0 \end{cases} \tag{4}$$

Multiplying a payment (=Sc) by $PWF(i,n)$, it is possible to obtain the present worth of the series of n such payments over n periods, i.e.

$$V = S_c PWF\,(i,n) \tag{5}$$

The above-defined present worth factor can be used to find the periodic loan repayment on a fixed-rate mortgage, which involves a series of n equal payments over the lifetime of the loan. Since all mortgage payments are equal, the periodic loan payment is given by:

$$S_c = \frac{V}{PWF(i,n)} \tag{6}$$

Taking inflation into account, the amount S has to be deflated at a fixed percentage. In the present work, the terms 'g' (common inflation rate) and 'e' (inflation rate of principal energy sources), will be clearly distinguished. So, introducing the concept of effective or real discount rate i', the expression (1+i) can be modified as:

$$(1+i) = (1+i')(1+g) \tag{7}$$

or

$$(1+i') = \frac{(1+i)}{(1+g)} \tag{8}$$

Thus, estimating amount S to be paid over the years n (at an effective discount rate i'), its present worth can be obtained using the expression

$$V = \frac{S}{(1+i')^n} = S\left[\frac{(1+g)}{(1+i)}\right]^n \quad (9)$$

The present worth of a series of payments to be made, in the presence of inflationary phenomenon, i.e. $g \neq 0$, is given by:

$$V = S_1\left[\frac{(1+g)}{(1+i)}\right] + S_2\left[\frac{(1+g)}{(1+i)}\right]^2 + ...+ S_n\left[\frac{(1+g)}{(1+i)}\right]^n = \sum_{k=1}^{n} S_k\left[\frac{(1+g)}{(1+i)}\right]^k \quad (10)$$

In case all mortgage payments are equal, the equation (10) can be written as:

$$V = S_c\sum_{k=1}^{n}\left[\frac{(1+g)}{(1+i)}\right]^k = S_c\sum_{k=1}^{n}\left[\frac{1}{(1+i')}\right]^k = S_c PWF(i',n) \quad (11)$$

Here the term $PWF\ (i',n)$, i.e. General Present Worth Factor (in the presence of inflationary phenomenon), is given by:

$$PWF(i',n) = PWF(i,g,n) \quad (12)$$

Using the previous definition of $PWF\ (i',n)$, we get:

$$PWF(i,g,n) = \sum_{k=1}^{n}\left[\frac{(1+g)}{(1+i)}\right]^k = \sum_{k=1}^{n}\frac{1}{(1+i')^k} \quad (13)$$

Applying the properties of geometrical series, we have:

$$PWF(i,g,n) = \frac{1-\left(\frac{1+g}{1+i}\right)^n}{\left(\frac{1-g}{1+g}\right)} \qquad \text{if } i \neq g \quad (14)$$

$$PWF(i,g,n) = n \qquad \text{if } i = g \quad (15)$$

$$PWF(i,g,n) = \frac{1-(1+i)^{-n}}{i} \qquad \text{if } g = 0 \quad (16)$$

2.1 Methodologies Available for Economic Analysis [8-12]

For correct sizing of a solar plant it is necessary that economic optimisation be done over its total life. It is, therefore, necessary to do both an analysis of the investment and returns from the plant over its foreseen lifetime period. For this purpose a varying economic index must be considered while calculating the amount spent and money received over the years. Irrespective of the investment type, economic analysis could be performed based on the concept of either arithmetic criteria or present worth. The first one is associated with the measuring methods that directly or indirectly find their application in the evolution of investment and financial recovery flow projected over the time. Simplicity, ability to provide a quick idea about a profitable investment, and absolute value of the recovery flow (though obtainable over long period), are the salient features of above–mentioned criteria but their failure to predict their present worth, is a major drawback.

Generally, Life Cycle Cost (*LCC*) approach is used for the solar process economics. This method provides a means of comparison of future costs with today's cost. This is done by discounting all anticipated costs to the common basis of the present worth. The incoming financial flow values are based upon the average increase in the market discount rate. Concepts of recovery period, profitability index and average profitability rate are presented within first criteria whereas Net Present Value (*NPV*) and Estimated Recovery Period correspond to the method based on the concept of present worth. The amount available during the year (D_k) is given by:

$$D_k = R_k - C_k \tag{17}$$

Cash flow (F_k) is the difference between the amount available and investment made during that period, i.e.

$$F_k = D_k - I_k \tag{18}$$

In case there is only the initial investment (D_k)**,** cash flows are equal to the amount available. The balance in the year (U_k) is given by:

$$U_k = F_k - A_k \tag{19}$$

Cash flow (F_k) and balance (U_k) can be considered as gross amount or net of the direct tax.

2.2 Simple Payback Time

The simple payback time represents the number of years necessary to recover the initial investment. The basic premise of the payback method is that the more quickly the cost of an investment can be recovered, the more desirable is the investment. In other words, it means the time until the profits expected from the investment (sum of cash flows) equals the tied up investment, i.e.

$$\sum_{k=1}^{RP} F_k = I_0 \tag{20}$$

If the annual cash flows are equal and constant ($F_1 = F_2 = F_3 \ldots\ldots = F_c$), Recovery Period (*RP*) is obtained from the expression:

$$RP = \frac{I_0}{F_c} \tag{21}$$

The simple payback method is not an appropriate measure to compare different projects from the profitability point of view. Rather, it is a measure of time in the sense that it merely indicates how many years are required to recover the investment for one project compared to another. As such, simple payback should not be used as the primary indicator to evaluate a project. It is, however, useful as a secondary indicator to indicate the level of risk of an investment. A further criticism of the simple payback method is that it does not consider the time value of money, or the impact of inflation on the costs.

2.3 Return on Investment (ROI)

Return on Investment is the average recompense of the capital invested and is given by the ratio between average calculated incomes to the initial investment, i.e.

$$ROI = \frac{\frac{1}{n}\sum_{k=1}^{n}(F_k - A_k)}{I_0} \tag{22}$$

This method of analysis compared to the precedent though provides an efficiency index of the invested capital but doesn't take into account the variable 'time period'.

2.4 Net Present Value (NPV)

The Net Present Value (*NPV*) of a project is the value of all future cash flows, discounted at the discount rate, in today's currency. Under the NPV method, the present value of all cash inflows is compared against the present value of all cash outflows associated with an investment. The difference between the present values of these cash flows, called the *NPV*, determines whether or not the project is generally an acceptable investment. Positive NPV values are an indicator of a potentially feasible project. The Net Present Value (*NPV*) is given by:

$$NPV = -I_0 + \sum_{k=1}^{n} \frac{F_k}{(1+d)^k} \tag{23}$$

If the cash flows over the year are constant (=*Fc*) then *NPV* is modified as:

$$NPV = -I_0 + F_C \sum_{k=1}^{n} \frac{1}{(1+d)^k} = -I_0 + F_C \cdot PWF(d,0,n) \tag{24}$$

In case, when all the items contributing to the net cash flows depends upon the same inflation rate (*g*), the prediction about the cash flow could also be effected with the effective discount rate (*d'*):

$$d' = \frac{d-g}{1+g} \tag{25}$$

However, considering the returns linked to the increase in tax on energy and costs related to the general inflation rate (*g*), predicted *NPV* with effective discount rate is given by:

$$NPV = -I_0 + \sum_{k=1}^{n} R_k \left(\frac{1+e}{1+d}\right)^k - \sum_{k=1}^{n} (C_k + I_k)\left(\frac{1+g}{1+d}\right)^k \tag{26}$$

If the economic variables are constant (annually) then *NPV* becomes:

$$NPV = -I_0 + R_C \cdot PWF(d,e,n) - (C_k + I_k) \cdot PWF(d,g,n) \tag{27}$$

As said above, a project is feasible if $NPV > 0$. It is advisable to select a project having higher *NPV* value. The present method though correct and very efficient to appraise the investment, depends significantly on the customer discount rate (*d*).

2.5 Discounted Payback Time

Conceptually, the method is similar to that of the simple payback time but differs in the sense that here costs and benefits are verified considering the principle of estimation. In order to determine this parameter, i.e. discounted payback time, it is essential to solve the equation given below:

$$NPV(n) = 0 \tag{28}$$

Considering both cash flow and annual flow to be constant (= *Fc*), we have:

$$I_0 = (R_C - C_C - I_k)\frac{1-(1+d)^{-RP}}{d} \tag{29}$$

Hence:

$$RP = \frac{\ln\left[\frac{1}{1-dI_0/(R_C - C_C - I_C)}\right]}{\ln(1+d)} \tag{30}$$

2.6 Economic Optimisation of Solar System [13]:

As mentioned earlier, solar systems are characterised by higher investment (linked directly to the collector area) and low operating cost. It is, however, to be noted that a solar system designed to meet total energy requirem ents ($f = 1$) can never be feasible, economically. From economic feasibility point of view, it is important that due consideration should be given to the integrated solar systems where a fraction of thermal load is supposed to be derived from a conventional plant. Collector area (*Ac*) is the principal design parameter of a solar water heating system [14]. It is true that the amount of energy collected increases with the increase in collector area but such increase in the collector area will certainly be having direct impact on the overall total cost of the system.

It is, therefore, necessary that for both the Net Present Value to be maximum and global cost minimum, due consideration be given to the collector area. The above-mentioned value can be calculated using the method of Life Cycle Cost (*LCC*). Global Cost (C_G) of an integrated solar system over its life period can be estimated using the equation[15-16]:

$$C_G = C_S P_1 + A_C E_C c_e P_2 + \frac{(1-f) L\, c_i P_3}{\eta_g} \tag{31}$$

Where C_S is the initial cost investment for solar part expressed as a sum of two terms. The first term (C_V) is proportional to the collector area whereas the second one (C_F) is a fixed amount. Hence:

$$C_S = C_V A_C + C_F \tag{32}$$

Here, the term C_V comprises of the costs of collectors, storage tank and structures, i.e.

$$C_V = C_C + C_{PS} + m \cdot c_a \tag{33}$$

where:

C_C = cost of collector;
C_{PS} = cost for the supporting structure, pumps and piping;
m = mass of the storage tank;
c_a = specific cost of the storage tank;
E_C = annual parasitic electric energy consumption for m^2 of collector area;
c_e = price of electric energy;
f = annual solar fraction;
L = annual thermal energy requirement;
c_i = cost of integrated energy;
η_g = global efficiency of the conventional plant.

It can be seen that the first term in equation (31) represents the cost proportional to the initial investment (*Cs*). Second term, often negligible, is the global cost of the unpredicted electric energy consumption (used to run the pumps in the case of forced circulation) whereas the third term is the overall integrated energy cost (electric power for a small system or gas or diesel oil for large-scale system). The parameter P_1 can be expressed as:

$$P_1 = \sigma(1-f) + (1-\sigma)(1-f)\frac{PWF(d,0,n_P)}{PWF(i,0,n_P)} + S_M PWF(d,g,n) + A_{SS} PWF(d,g,n) \tag{34}$$

where:

σ = fraction of the initial cost anticipated by the customer;
f = fraction of the initial cost as borrowed capital;
A_{ss} = fraction of the initial cost paid as insurance expenses during first year;
S_M = fraction of the initial cost paid as maintenance expenses during first year;
n_p = duration of the loan in years.

$\sigma(1 - f)$ represent the advance paid by the customer.

The term:

$$(1-\sigma)(1-f)\frac{FA(d,0,n_P)}{FA(i,0,n_P)}$$

is the global value estimated from the annual depreciation instalments (to be constants) for the return of bank loan.

On the other hand, the term $S_M PWF(d,g,n)$ is the estimated overall maintenance cost. Finally, the term $A_{ss} PWF\ (d,g,n)$ represents the estimated global insurance cost for the plant. Naturally, some of the terms in equation (34) could be neglected. For example, in the case of a private customer who doesn't apply for the bank loan and pays the whole initial cost in advance ($s = 1$), P_1 is just equal to the first term only (maintenance as well as insurance expenses to be negligible).

The parameter P_2 assigned to estimate the costs of energy both auxiliary and parasitic, is given by the expression:

$$P_2 = FA(d, e, n) \tag{35}$$

The criteria for the optimisation of a solar system require determining the area of collectors that minimises the overall cost (the value obtained using equation (31)). Following a number of mathematical operations, it is possible to obtain the expression for optimised collector area, as given below:

$$A_{opt} = \frac{c_2\ L\ c_i\ P_3}{(C_V P_1 + E_C c_e P_2)\eta_g} \tag{36}$$

3. ECONOMIC ANALYSIS OF A SMALL SIZED SOLAR WATER HEATING SYSTEM (A CASE STUDY, IN ITALY)

The results obtained from the economic analysis of a solar water heating system designed to satisfy the hot water requirements of four persons, are reported. The analysis has been performed for integrated solar water systems with different energy collecting typologies, i.e. flat plate or a vacuum tubular collector.

Considering the fact that economic analysis of an integrated solar water heating system is influenced by a number of factors such like type of collector used, local climatic conditions, cost of the energy replaced, etc., an attempt has been made to analyse the above-mentioned system giving due considerations to the factors mentioned above.

Here, annual solar fraction was calculated using *f*-Chart calculus method at typical reference parameters of a medium quality collector. Cost of the collector, back-up water heater, supporting structure, pumps and tubes, etc were fixed based upon the average values quoted by various Italian companies [17]. Other economic parameters are based upon the Italian Economic norms as on January 2000 [18-19].

The annual gains in terms of the cost of the energy furnished by the solar system and hence saved can be expressed as:

$$R_k = \frac{fL}{\eta_g} C_i (1+e)^k \tag{37}$$

Where C_i is the present cost of a unit of integrated energy. Year by year costs are represented by the sum of electric energy cost and maintenance cost, i.e.

$$C_k = S_M (1+g)^k \tag{38}$$

Other cash flows not being considered to be the annual investment are given by:

$$F_k = R_k - C_k \tag{39}$$

3.1 Integrated Flat Plate Solar Water Heating System

To begin with, initial data for the solar system under economic evaluation, is generated under separate data heads, i.e. Geographical, Design and Economic data.

3.1.1 Geographical Data

Name of the city	Latitude	Longitude
Bolzano	46° 53’ North	11° 26’ EAST
Rome	41° 54’ North	12° 30’ EAST
Nova Siri	40° 16’ North	16° 25’ EAST
Palermo	38° 11’ North	13° 06’ EAST

3.1.2 Design Data

Parameter	Value
Collector area	4 m^2
Daily water requirement/per person (Γ_{load})	40 litres
Specific heat of water (c_p)	4186 J/kg
Number of users	4
Minimum hot water temperature (T_u)	50°C
Inlet water temperature (T_i)	15 °C
Annual thermal load ($L = \Gamma_{load}\, c_p\, (T_u - T_i) \cdot 365 \cdot users$)	8556 MJ
Efficiency of conventional plant if constructed using a methane run back-up water heater	85%
Efficiency of conventional plant if constructed using an electric back-up water heater	95%
Plant’s economic lifetime	15 Yrs
Annual solar fraction in Bolzano	0.60
Annual solar fraction in Rome	0.73
Annual solar fraction in Nova	0.78

3.1.3 Economic Data

Parameter	Value
Collector cost	480000 lire/m^2
Cost relevant to the supporting structure, pumps and tube	110000 lire/ m^2
Maintenance cost (w.e.f. seventh years of installation)	40000 lire/year
Cost of the storage tank (assuming a tank capacity = 200 litres)	1500000 lire
Cost of integrated energy (auxiliary plant with a methane run back-up water heater)	23 lire/MJ
Cost of integrated energy (auxiliary plant with an electric back-up water heater)	95 lire/MJ
Interest rate	3 %
Inflation rate	2 %
Inflation rate relevant to the energy cost	2 %

1 Euro = 1936.27 lire

3.2 Flat Plate Solar Water Heating System with Electric Back-up Water Heater

As is evident from Figure 1, the status of Net Present Value (*NPV*) obtained for an electrically integrated flat plate solar water heating system, with identical technical and economic assumptions but operating under different climatic conditions, is quite different. For example, the net present value for the above-mentioned solar water heating system appears to be maximum when operated under the climatic conditions prevailing at the small town of Nova Siri, in Southern Italy. The results obtained can be justified considering the fact that the solar fraction recorded at Nova Siri is much higher compared to the values corresponding to other places.

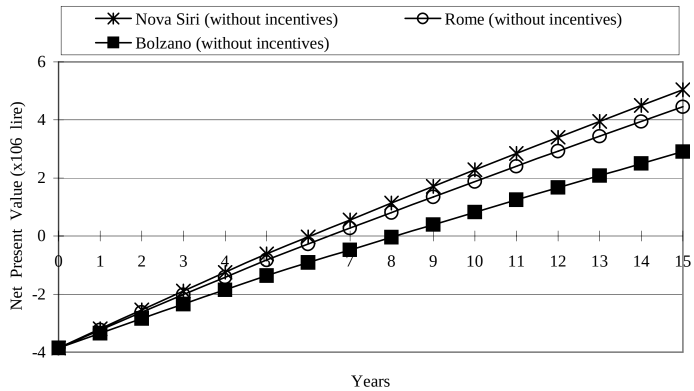

Fig. 1. Net Present Value as a function of time for a solar water heating system with an electric back-up water heater, operating under different climatic conditions, without incentives and with fixed collector cost of 480.000 Lit/m^2

It is further to be noted that in view of the additional incentives in accordance with Italian government law No. 488/99 [20] not only the net present value would be maximum but recovery period for solar water heating systems will also be reduced significantly. The results obtained from the economic analysis performed using such additional incentives (Figures 2-4) show that recovery period can be shortened further by nearly 2 and 3 years for a solar water heating system installed in Nova Siri, Rome and Bolzano, respectively.

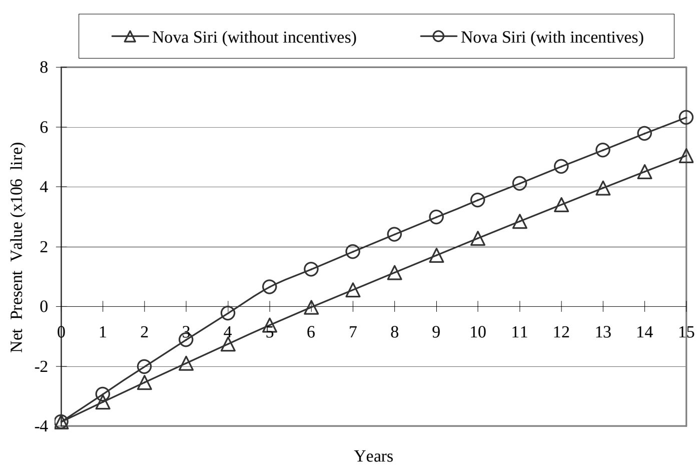

Fig. 2. Net Present Value as a function of time for a solar water heating system with an electric back-up water heater, installed in Nova Siri (with and without incentives in accordance with Italian law No. 488/99)

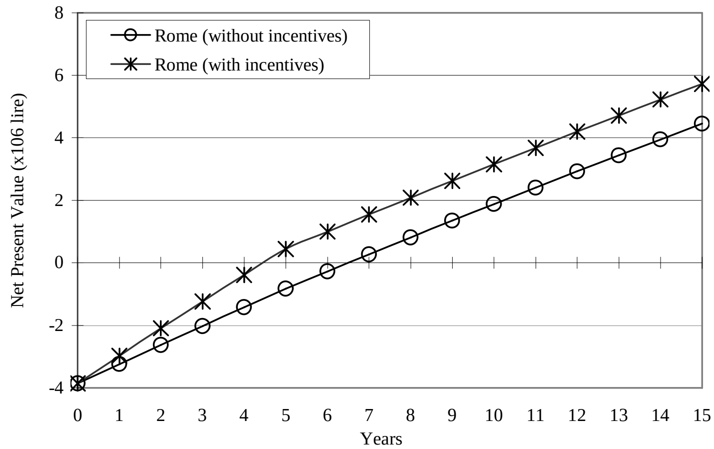

Fig. 3. Net Present Value as a function of time for a solar water heating system with an electric back-up water heater, installed in Rome (with and without incentives in accordance with Italian law No. 488/99)

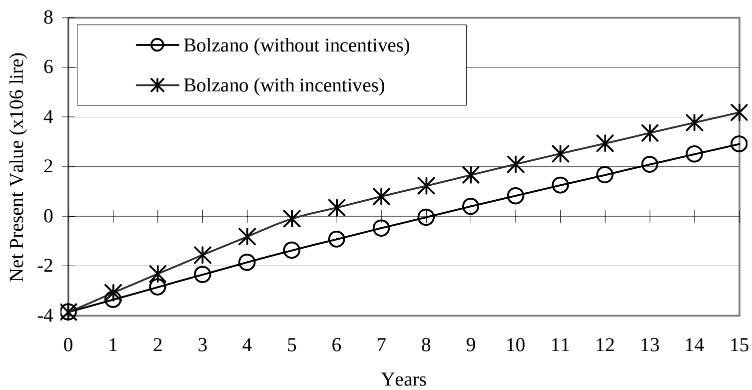

Fig. 4. Net Present Value as a function of time for a solar water heating system combined to an electric back-up water heater, installed in Bolzano (with and without incentives in accordance with Italian law No. 488/99)

Also, it has been observed that both the net present value and recovery period are affected by the variation in the prices of collector with time. How this factor affects the net present value relevant to a solar plant installed in Rome, has been demonstrated in Figure 5. It is evident from the results obtained that cost reduction and recovery period can be lowered approximately by a year.

It is hoped that if the amount offered in the framework of the Italian law no.488/99 (36% of total system cost to be recovered as tax deduction over five years period) were granted in the capital account, economic feasibility of the system under investigation would certainly be much better. The effect of different incentives policies, i.e. without incentive, 36% of total system cost to be recovered as tax deduction over five years period and 36% financial contribution from the sunk capital, on the net present value of an electrically integrated solar thermal plant installed in Rome, is shown in Figure 6.

It has been observed that the variation of incentive policies does not show any major effect on the net present value. However, Return on Investment (*ROI*) appears to be high in the case of incentive granted from sunk capital. The value for different economic parameters such as, *NPV*, *ROI*, Simple Recovery Period (*SRP*) and Estimated Recovery Period (*ERP*), are presented in Tables 1 and 2.

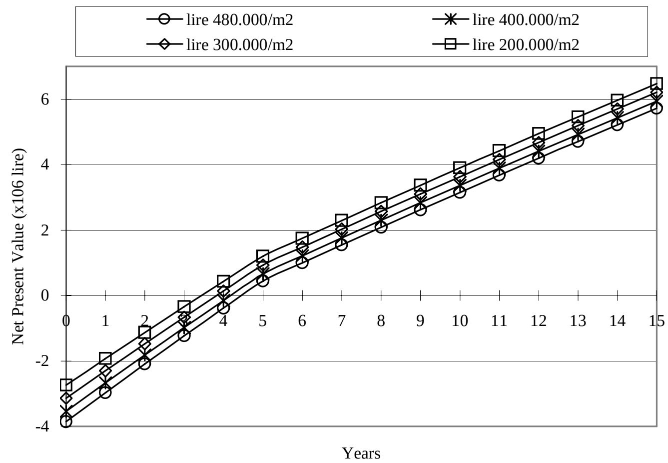

Fig. 5. Net Present Value as a function of time for a solar water heating system with an electric back-up water heater, installed in Rome (with and without incentives in accordance with Italian law No. 488/99 and varying collector values)

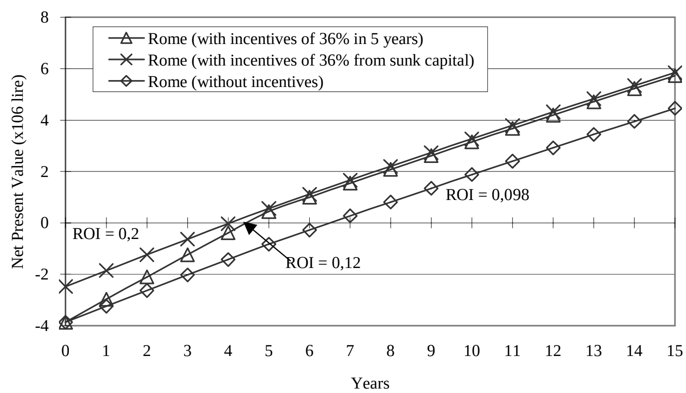

Fig. 6. Net Present Value as a function of time for a solar water heating system with an electric back-up water heater, installed in Rome (under different incentive options).

Table 1 Different Economic Parameters Predicted in the Case of a Flat Plate Solar Water Heating System with an Electric Back-Up Water Heater

Cost of collector = 480000 Lit/m²				
Location	**NPV (10^3 Lit)**	**ROI**	**RP_S (Years)**	**RP_D (Years)**
Bolzano*	2.907	0.06	7 - 8	8 - 9
Bolzano**	4.180	0.09	4 - 5	5 - 6
Rome*	4.452	0.10	5 - 6	6 - 7
Rome**	5.725	0.12	4 - 5	4 - 5
Nova Siri*	5.046	0.11	5 - 6	6 - 7
Nova Siri**	6.319	0.18	4 - 5	4 - 5

* (without incentives)

** (with 36% contribution in 5 years)

Table 2. Different Economic Parameters as a Function of Collector Prices. Predicted Data is for a Flat Plate Solar Water Heating System with an Electric Back-up Water Heater, Installed in Rome

Collector Cost (Lit/m^2)	Type of incentive	NPV (10^3 Lit)	ROI	RP_S (Years)	RP_D (Years)
480000	36% tax deduction in 5 years	5.725	0.122	4-5	4-5
480000	36% contribution from sunk capital	5.841	0.200	3-4	4-5
400000	36% tax deduction in 5 years	5.939	0.141	3-4	4-5
300000	36% tax deduction in 5 years	6.207	0.169	3-4	3-4
200000	36% tax deduction in 5 years	6.475	0.206	3-4	3-4

3.3 Flat Plate Solar Water Heating System with Methane Gas Back-up Water Heater

Considering the fact that methane gas is enormously diffused over the Italian territory, an effort has been made to analyse a solar water heating system connected to methane run back-up water heater installed in three different Italian cities i.e. Bolzano, Rome and Nova Siri. The results corresponding to the above-mentioned solar system installed in Bolzano, are presented in Figure 7. It can be observed that even assuming both the very low collector prices (200000 lire /m^2) and best incentive policy, net present value appears to be negative. In view of the fact stated above it can be concluded that investment on a solar water heating system backed by a methane run back-up water heater and operating in Bolzano, can never be profitable.

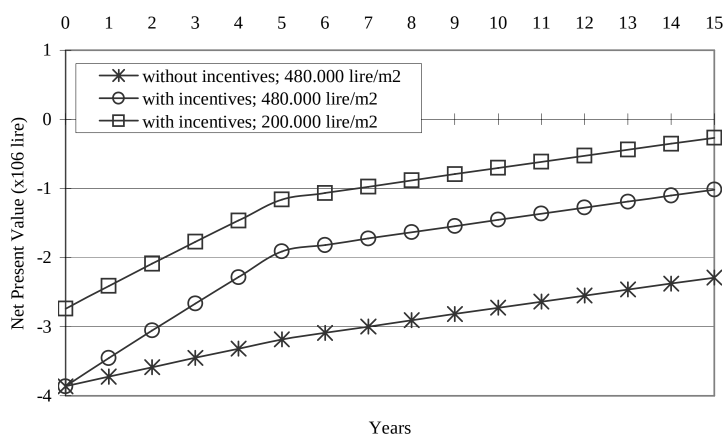

Fig. 7. Net Present Value as a function of time for a solar water heating system with a methane run back up water heater, installed in Bolzano (with and without incentives in accordance with Italian law No. 488/99 and varying collector values)

Net Present Value (with the variation of collector price) for Identical system when installed in Rome and Nova Siri, appears to be positive (Figures 8-9). It is, however, to be noted that while in Rome the above-mentioned result is possible with minimum collector price (per square metre) of lire 200000 and incentives foreseen in accordance with Italian law No. 488/99, at Nova Siri the same can be achieved with the same incentive but even at a minimum collector price (per metre square) of lire 300000, also.

From the above discussion, it can be concluded that, though the Net Present Value (*NPV*) is positive in both the cases but with investment recovery period of the order of nearly 14 – 15 years (mainly due to lower methane prices), a potential customer is generally very reluctant towards this particular investment. The same, however, will not be true when either methane would be more costly or so-called "carbon tax" is introduced [21].

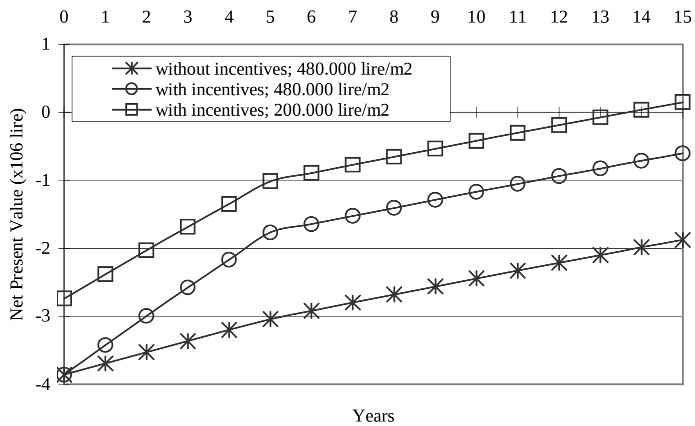

Fig. 8. Net Present Value as a function of time for a solar water heating system with a methane run back up water heater, installed in Rome (with and without incentives in accordance with Italian law No. 488/99 and varying collector values)

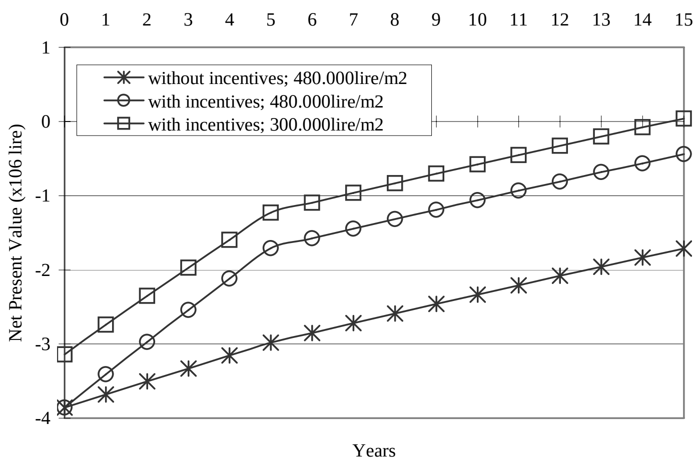

Fig. 9. Net Present Value as a function of time for a solar water heating system with a methane run back up water heater, installed in Nova Siri (with and without incentives in accordance with Italian law No. 488/99 and varying collector values)

3.4 Evacuated Tubular Solar Collector with Electric Back-up Water Heater

Economic analysis of solar water heating system with evacuated tubular collector is conducted using identical data both design and economic (discussed above on the section on flat plate solar water heating system except few changes relevant to evacuated tubular collector, as given below:

- Cost of collector = 1000000 lire/m^2

- Annual solar fraction at Bolzano = 0.80
- Annual solar fraction at Nova Siri = 0.92

The analysis has been performed for solar water heating systems installed at Bolzano and Nova Siri. It is to be noted that owing to the high solar fraction of evacuated tubular collectors their cost is nearly double that of the flat plate collectors of comparable size. Net Present Value (*NPV*) corresponding to the above-mentioned system operating in Bolzano assuming different incentives policies (without incentives, with incentives foreseen in accordance with Italian law No. 488/99 and 36% contribution from sunk capital), is shown in Figure 10.

Frankly speaking though the net present value does not differ significantly with corresponding variation in the incentive policies, with the incentive in the form of 36% contribution from sunk capital showing better ROI value. As shown in Figure 11, the same is true in the case of another solar system installed at Nova Siri. The corresponding results for the above-discussed solar system installed at Bolzano and Nova Siri, are presented in Table 3.

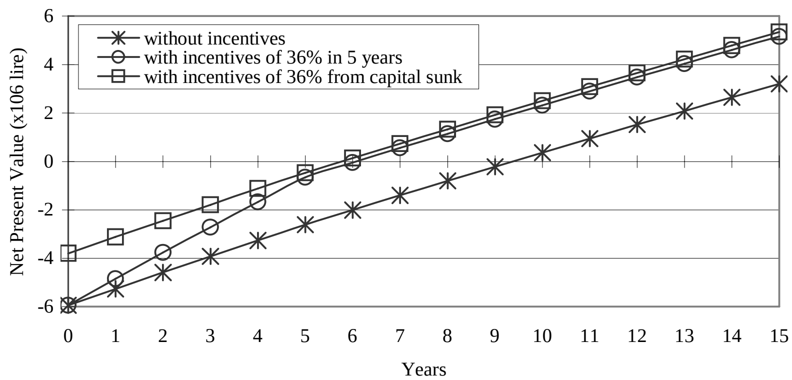

Fig. 10. Net Present Value as a function of time for a solar water heating system with an electric back up water heater, installed in Bolzano (under different incentive options)

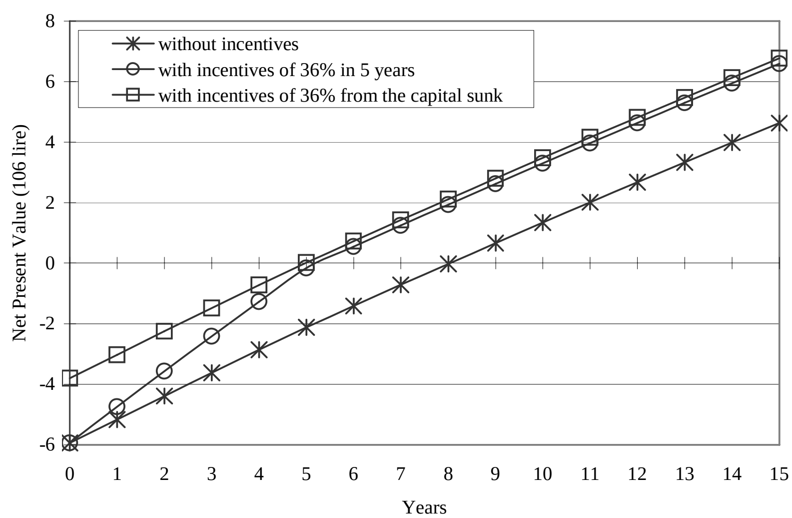

Fig. 11. Net Present Value as a function of time for a solar heating system with an electric back-up water heater, installed in Nova Siri (under different incentive options)

Table 3. Values for Different Economic Parameters Predicted in Case of an Evacuated Tubular Solar Collector with an Electric Back-Up Water Heater

Cost of collector = 1.000.000 Lit/m²				
Location	**NPV (10^3 Lit)**	**ROI**	**RP_S (Years)**	**RP_D (Years)**
Bolzano*	3.203	0.046	8 – 9	9 – 10
Bolzano**	5.162	0.070	5 - 6	6 – 7
Bolzano***	5.342	0.119	5 - 6	5 – 6
Nova Siri*	4.629	0.066	7 – 8	8 – 9
Nova Siri**	6.588	0.090	4 – 5	5 – 6
Nova Siri***	6.767	0.151	4 - 5	4 – 5

* (without incentives)
** (with 36% contribution in 5 years)
** (with 36% contribution from sunk capital)

3.5 Evacuated Tubular Solar Collector with Methane Gas Back-up Water Heater

The results obtained from the economic analysis performed on the above-mentioned solar system with a methane back-up water heater and installed both in Bolzano and Nova Siri, shows that even assuming very low collector price (600000 lire/m^2) as well as best incentive policy, not only the net present value appears to be negative but simple recovery period is so high (> 15 years) that investment on such a system, (i.e. an evacuated tubular solar collector integrated with methane supply and operating at either places both Bolzano and Nova Siri), under no circumstances could be profitable. In view of the facts stated above, it can be concluded that the above-mentioned solar thermal systems can't compete with the traditional water heater working with methane gas. This can mainly be attributed to the high cost for each kWh produced using an evacuated tubular collector combined to a methane run back-up water heater.

3.6 Solar Thermal System with Methane Gas Back-up Water Heater for Sanitary Water Heating

Economic analysis of a solar water heater combined to methane run back-up water heater, designed to meet the hot water requirement of a tennis club at Palermo, Southern Italy, is discussed below. It is to be noted that for the Annual Global Cost to be minimum, it is very important that precise calculations are made to define the optimal surface area (A_{opt}), in the design phase. It is in the above reference that data relevant to the annual solar fraction as a function of the number of collectors used (i.e. net absorber surface area) at the installation site, e.g. Palermo in the present case (Figure 12), is very important.

Theoretical prediction of Annual Global Cost as a function of the number of collectors used, assuming methane as the integrated energy resource and cost of solar collector under investigation of approximately 500000 lire/m^2, is presented in Figure 13. It is evident that the number of collectors at which the minimum Annual Global Cost would be obtained, is 60. Considering the fact that each collector has a surface area of nearly 2.08 m^2, the optimal surface area of the system under the above-mentioned assumptions is approximately 125 m^2.

Figure 14, on the other hand shows the Annual Global Cost as a function of the number of collectors under varying collector cost/m^2. The values for the optimal surface area corresponding to the data presented in Figure 14 (determined at different system cost), are shown in Table 4.

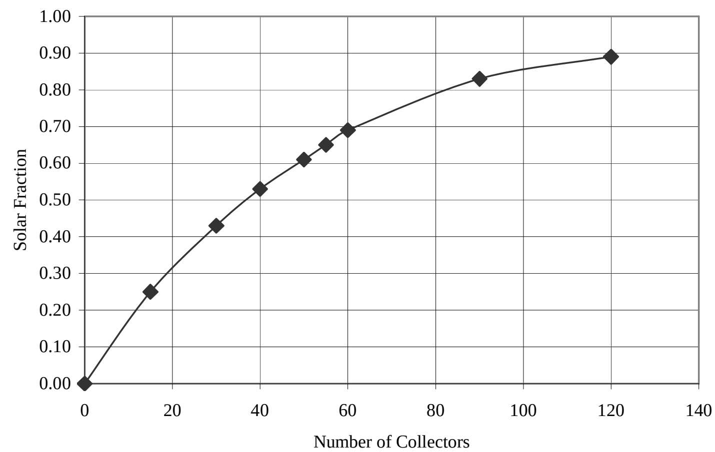

Fig. 12. Annual solar fraction as a function of number of collectors (in Palermo)

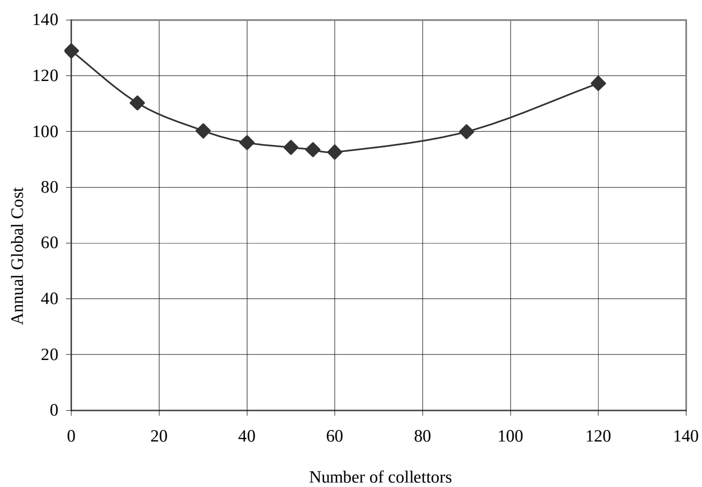

Fig. 13. Annual global cost of a solar heating system as a function of number of collectors (considering auxiliary energy source to be methane gas and cost of system = lire 500.000/m2)

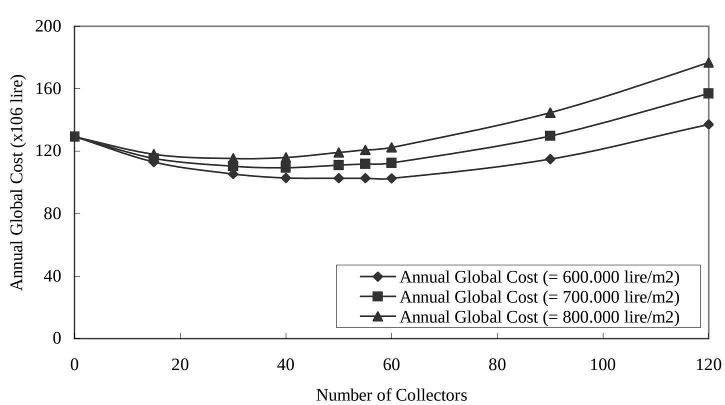

Fig. 14. Annual global cost of a solar heating system as a function of number of collectors (considering auxiliary energy source to be methane gas and cost of system/m^2 to be variable)

Table 4. Optimal Surface Area as a Function of System Cost (Methane Integration)

Contribution toward the capital cost (Percentage of total system cost) = 30%	
Cost of the System (lire/m^2)	**A_{opt}** (m^2)
500.000	125
600.000	105
700.000	83
800.000	62

Theoretical prediction of Annual Global Cost as a function of the number of collectors used, assuming diesel oil as the integrated energy resource and solar collector cost of approximately 500000 lire/m^2, is presented in Figure 15.

It can be observed that under above-mentioned assumptions, optimal solar collector area (or number of collectors) at which the Annual Global Cost resulted to be minimum, is approximately 187 m^2 (90 collectors). Here, cost of the integrated energy being high (almost double that of the methane) it was advisable to cover the maximum energy demand using solar thermal plant thus requiring higher optimal area. Once optimal surface area is defined, the next step is to conduct economic analysis considering different forms of financial contributions (incentives) available.

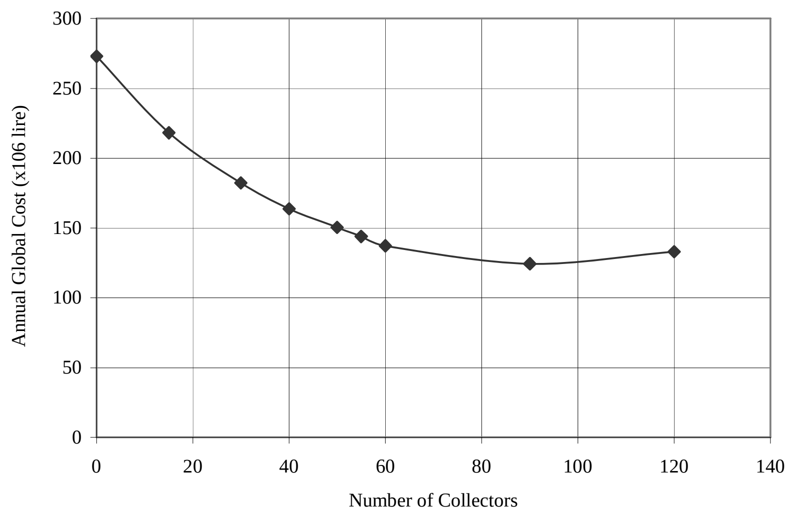

Fig. 15. Annual Global Cost of a solar heating system as a function of number of collectors (considering auxiliary energy source to be diesel fuel and collector cost of lire 500.000/m2)

The effect of different incentives on the Net Present Value (NPV) relevant to a solar water heating system combined to a methane run back-up water heater installed at Palermo, is shown in Figure 16.

Here, the contribution from the European Community (CE) depends on the quantity of energy effectively furnished by the solar system [22]. CE incentives valid for a period of eight years are in the form of a financial contribution of lire 50 for each kWh of energy produced from a solar system. It is obvious that the type of incentives considered is of vital importance both for Net Present Value (NPV) and the Real Recovery Period. The values of the different economic parameters obtained as a function of various incentive policies applied for the solar system integrated either to a methane or diesel run back-up water heater, are shown in Tables 5 and 6, respectively. It is to be noted that CE incentives compared to CC incentives produces a significant rise in all the economic parameters of solar system irrespective of the integration resource.

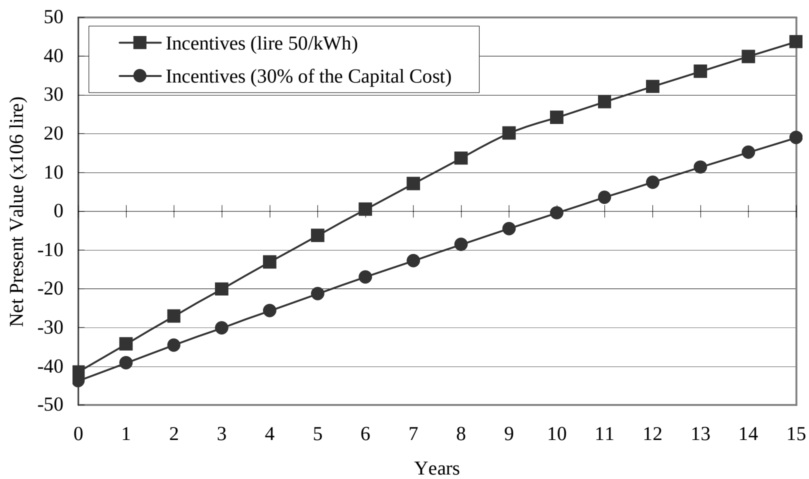

Fig. 16. Net Present Value as a function of time with different incentive options (considering auxiliary energy source to be methane gas and European Community incentives of lire 50/kWh for a period of eight years)

Table 5. Economic Parameters with Different Incentives Relevant to a Solar Water Heating System with Methane Gas Back-Up Water Heater

Integrated to Methane Gas (Cost of the system: lire 500.000/m2)					
	Aopt (m2)	**Total Cost** ($x10^6$ lire))	**VAN** ($x10^6$ lire)	**ROI**	**TRa** (Years)
Incentives of 30% of the Capital Cost	125	43,8	19	0,04	10
Incentives of lire 50/kWh	83	41,5	44	0,09	6

Table 6. Economic Parameters with Different Incentives Relevant to a Solar Water Heating System Integrated with Diesel Fuel

Integrated to Diesel Fuel (Cost of the system: lire 500.000/m2)					
	Aopt (m2)	**Total Cost** ($x10^6$ lire))	**VAN** ($x10^6$ lire)	**ROI**	**TRa** (Years)
Incentives of 30% of the Capital Cost	187	65,4	152	0,20	4-5
Incentives of lire 50/kWh	146	73	160	0.21	4

Following data has been used for the economic analysis (using Actual Global Cost method).

Parameter	**Value**
Collector surface area	2.08 m^2
Cost of solar system (inclusive of costs relevant to the collector, storage tank, supporting structure, pumps and piping)	500000 lire/m^2
Maintenance cost	1% of system cost
Cost of integrated energy (auxiliary plant with a methane back-up water heater)	82 lire/kWh
Cost of integrated energy (auxiliary plant with diesel oil back-up water heater)	173 lire/kWh
Cost of electric energy	340 lire/kWh
Annual energy loss (where 'f' is the annual solar fraction and the factor (f*L) represent thermal load to be covered by the solar energy)	1% (f*L)
Interest rate	3.5 %
Inflation rate	2 %
Inflation rate relevant to the energy cost	2%
Solar fraction as a function of number of collectors	See Fig 12
Annual energy requirement	100000 kWh
Economic lifetime	15 Yrs
Contribution toward the capital cost	30% of total cost
Efficiency of conventional plant if constructed using a methane back-up water heater	85%
Efficiency of conventional plant if constructed using a diesel oil back-up water heater	85%

Net Present Value (*NPV*) for a solar system combined either to a methane or diesel run back-up water heater but with 30% contribution from the sunk capital, is presented in Figure 17. Results presented in Figure 18 correspond to a similar system but incentive in the form of CE (i.e. financial contribution of 50 lire/kWh for a period of 8 years).

Analysis of the data shows that a solar system is competitive whether it is combined to a methane or diesel oil resource though the profitability rises significantly in the case of solar system combined to the diesel oil resource. It is mainly due to the higher cost of diesel oil compared to the methane.

It is, however, to be noted that in addition to the above-mentioned economic parameters, a solar system also provides energy and numerous environmental benefits. For example, the amount of principal energy saved annually is given by:

$$R_{prim} = \frac{f \cdot L}{rend} \tag{40}$$

where rend is the substituted fuel efficiency. Pollutant gases emitted annually/life cycle (in tonnes):

$$R_{emis} = \frac{F_{comb} \cdot f \cdot L}{rend} PWF(i, n) \tag{41}$$

Where F_{comb} is the emission factor of the substance considered to substitute the fuel. Specific emission factor of CO_2 in the case of both diesel oil and methane, are presented in Table. 7.

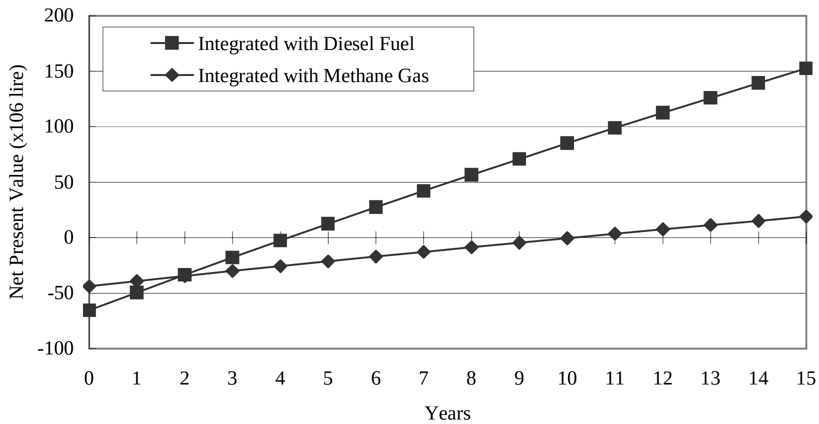

Fig. 17. Net Actual Value as a function of time with different auxiliary energy resources and 30% incentives in CC

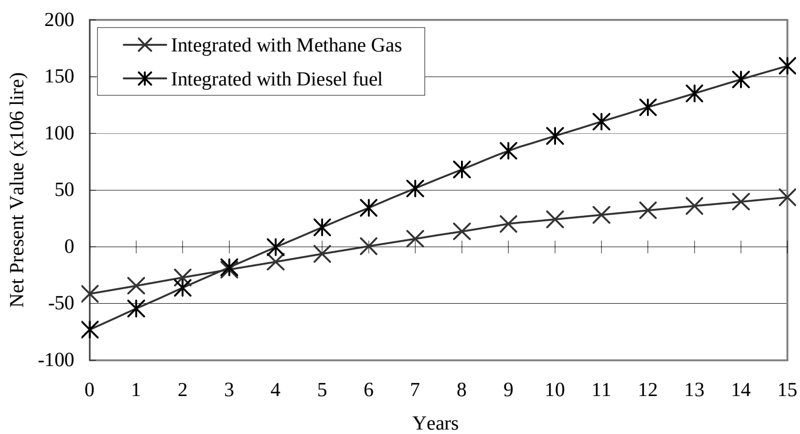

Fig. 18. Net Present Value as a function of time with different auxiliary energy resources and C incentives (lire 50/kWh for a period of 8 years)

Table 7 Amount of Principal Energy Saved and Emission of CO_2 Avoided Annually during Its Life Cycle, with Different Integration Resource

	Rprim. (kWh/year)	**Remiss. (CO_2)** (in Tonnes)
Integrated to Methane	81176	216
Integrated to Diesel oil	97647	393

4. CONCLUSIONS

Italy both due to high solar insolation levels and high-energy cost has highest potential for solar thermal systems. In the last few years thanks to the valuable support from the national Environmental Ministry, the Italian solar thermal market has had one of the highest growth rates in Europe. Increased awareness for the need of energy saving, more attractive financial offers for end-consumers and public support programs, have been the key factors for the positive developments. From economic feasibility point of view, it is important that due consideration should be given to the integrated solar systems where a fraction of thermal load is furnished from a conventional plant. Based upon the results reported in the present papers, the following important conclusion could be drawn:

- Economic evaluations depend not only on the technology and climate but also on all the specific financial assumptions like cost of the conventional energy replaced, interest rate, VAT reduction on solar thermal products and services, economic incentives (if any) as well as associated environmental benefits and energy conservation, etc.
- The results obtained from the techno-economic analysis conducted on solar water heating systems designed to fulfil hot-water requirements of a small family shows that such systems (without financial incentives) could be cheap only when used to replace traditional electric back-up water heater.
- On the other hand, both negative Net Present Value and high simple recovery period of nearly 15 years or so (even at very low collector prices as well as best incentive policies) obtained from the economic analysis conducted on the flat plate as well as evacuated tubular solar thermal system integrated with methane supply, simply make such systems, non profitable.
- Consequent economic evaluations are indicative of the changes that other countries can expect if they can adopt similar incentives.

5. ACKNOWLEDGEMENTS

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6. NOMENCLATURE

I_0 = Initial investment
I_k = Investment in the year k
I_c = Annual investment (constant)
R_k = Return in the year k
R_c = Annual return (constant)
C_k = Expense in the year k
C_C = Annual cost (constant)
D_k = Amount available in the year k
D_C = Funds available annually (constant)
F_k = Cash flow in the year k
F_C = Annual cash flow (constant)
A_k = Depreciation in the year k
A_C = Annual depreciation (constant)
U_k = Balance in the year k
U_C = Annual balance (constant)
i = Nominal interest rate

g = Common inflation rate
e = Inflation rate of the price of energy
d = Customer discount rate
n = Economic lifetime of the plant

7. REFERENCES

[1] Jelen F.C., "Cost and optimisation of engineering", New York: McGraw-Hill, 1970.
[2] Gerrett, D.E., "Chemical engineering economics". New York: Van Nostrand Reinhold, 1989.
[3] Beckman et al., VTT research report no. 697, VTT, Espoo, Finland, 1990.
[4] Beckman D, Graham R. In: Bridgwater A.V., editor. Advances in thermochemical biomas conversion, Glasgow: Blackie Academic and Professional; 1993, 1314-24, 1993.
[5] Diebold J.P. et al. In: Bridgwater A.V., editor. Advances in thermochemical biomas conversion, Glasgow: Blackie Academic and Professional; 1993, 1325-42, 1993.
[6] Mitchell C.P., Bridgwater, A.V., Stevens, D.J., waters, M.P. Biomass Bioene, 9(1-5), 205-26, 1995.
[7] Mesko, J.E., Economic evaluation of various cogeneration systems for a large university campus. ASME Cogen-Turbo, 6, 87-94, 1991.
[8] Hausermann, W.B. Report no. 95-EERC-08-04, University Dakota, September 1995.
[9] Bridgwater, A.V., Fuel, Vol. 74(5), 631-653, 1995
[10] International Energy Agency, Energy Prices and Taxes, 4yh Quarter, 1998.
[11] Gerrard A.M, editor, A guide to capital cost estimating, London; U.K. Institution of Chemical Engineers, 2000.
[12] OECD, Main economic indicators, 1986-2000. Paris:OECD, 2000
[13 Brandemuehl M.J., Beckman W.A.: "Economic Evaluation and Optimisation of Solar Heating System", *Solar Energy*, 1979, 23.
[14] Barley C.D., Winn C.B.: "Optimal Sizing of Solar Collector by the Method of Relative Areas", *Solar Energy*, 1978, 21, 279.
[15] Cucumo M., Marinelli V.: "Metodi di Valutazione ed Ottimizzazione Economica degli Impianti Solari", *Energie Alternative HTE*, 1989, 57, 11.
[16] Cucumo M., Marinelli V. and Oliveti G., "Ingegneria Solare Principi ed Applicazioni", Pitagora Ed. Bologna, 1994.
[17] Adiconsum, "La guida del Consumatore", No. 14, aprile 1999.
[18] Internet site http://www.republica.it/, 2000.
[19] Internet site http://www.utorita.energia.it/, 2000.
[20] Internet site http:/www.isesitalia.it/, 2000.
[21] Cesarei, C.M., "Fiscalità ed energia". Conferenza Nazionale Energia e Ambiente, Roma (Italia), 1998.
[22] Valentini, G., "Uno strumento di ingegneria finanziaria promosso dalla CEE: il finanziamento tramite terzi", ed ENEA, Roma 1993.