TECHNO-ECONOMIC STANDING OF SOLAR THERMAL TECHNOLOGIES BELOW 100 ^{o}C

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Abstract

Non-tracking collectors are the important technological options to harness the solar thermal energy at temperature below 100^{o}C. Thermal energy below this level has very wide applications in the residential and industrial sectors. Also, energy at this level can be used indirectly to produce cooling, configuration and cost were considered and their energy collection with different design, configuration and cost were considered and their energy collection capabilities were estimated under the Ethiopian conditions for different applications identified with the temperature. Based on the manufactures' quotations and other economic parameters, the annual amortized cost of solar collectors were estimated. These values were used to estimate the system cost per unit of energy generation. A domestic solar water heater with an unglazed collector is the only solar system having economic viability at present. Evacuated tube collectors stand a good chance of being economically viable in future with increase in fuel prices and/or reduction in system cost.

Key words:

Collector, Solar thermal technology, renewable energy, non -tracking collectors, Flat collectors

Techno Economic analysis, thermal energy, domestic solar water, solar driers

INTRODUCTION

Solar energy is incident on the earth's surface at the rate of approximately $8x10^{16}$ **W**. This freely available energy is more than 10,000 times the present level of the global worldwide energy consumption. In order to be useful, however, this energy must be collected and brought to the right place at the right time. Also, the cost of the equipment needed to collect it and convert into useful form is important. Even though sunlight is free and available in plenty, one must pay a capital charge for amortization of the equipment. This makes the solar energy capital intensive.

Solar energy can be effectively collected by non-concentrating collectors or a solar pond with reasonably good efficiency at temperatures below 100°C. This thermal energy in its simplest and direct form can be used to meet the domestic and industrial hot water needs and space heating requirements during the winter season. Also, it can be used for the production of cooling, fresh water and electricity. These indirect applications involve additional hardware and a thermodynamic process having a low conversion efficiency. These factors affect the end product cost considerably and make solar systems uncompetitive with conventional systems.

Technological development in the last two decades can be successfully used to harness solar energy for any of the aforementioned applications. Today, practically every country around the world has functional solar systems making hot water, producing cooling and fresh water and generating electricity. Some of the solar components such as the solar water heater are easy to generating electricity. Some of the solar components such as the solar water heater are easy to fabricate and require only simple machines and technical skills. These systems are manufactured in over 50 countries all over the world.

The sudden rise of oil prices in 1973 gave a tremendous Impetus to solar energy utilization. A worldwide interest was developed to harness this abundantly available, free source of energy.

Leading institutions in the major industrialized countries were assigned with the exclusive responsibility to develop suitable hardware. It was a golden period for the solar energy utilization. Tall promises were made by the scientists and the solar experts, and it was apparent, in those days, that it was to be the energy for the future. This situation changed sharply through the late seventies and early eighties when the oil prices not only stabilized, but began to fall. Today it is a different situation. Climate change is a reality now impacting both the developed and developing countries. The countries should therefore take into account the adverse impacts of climate change across various sectors of their economies and try to build in appropriate redressed measures so as to minimize the loses. Multi environment agreement provide opportunities to catalyze such measures Fore example the CDM(clean development mechanism)of the united nations frame work convention on climate change(UNFCCC) is already in place and several counties and industries have gained out this mechanism. By implementing clean and environmentally round development practices. The is a global business model under the KYOTO PROTOCAL that enables project developers to receive carbon credits towards their green house gas(GHG) emission reduction. Ethiopia being one of the non- carbon emission countries, the investors in this sector can additionally benefit from the CDM.

How ever the latest COP15 meeting at Denmark has opened up a need for even countries like Ethiopia to take pre-emptive actions in conserving energy, reducing their carbon foot prints and GHG emissions thus opening up a huge market for these services in next five year across the country and the world.

The COP15 program regarding countries like Ethiopia recommends covering the following:

- Understanding climate change challenge and environmental uses
- Clean development mechanism (CDM) and its back ground.

- Post cooperation opportunities
- National action plan on climate change (NAPCC)
- Increase scope of carbon trading in the fight of Ethiopian commitment to reduce the carbon intensity of its economic growth
- Active public –private partnership (PPP) in CDM
- CDM opportunities for various sectors in Ethiopia
- Energy efficiency eligible projects
- CDM modalities and procedures
- CDM project cycle
- Validation and verdict ion issues
- Gold standard CDM
- Carbon foot printing
- Carbon tracing.

The carbon market is growing in leaps and bounds. Ethiopian industries are quite pro active in generating awareness amongst its customers and realizing carbon credits the present CDM market potential is around 30 billion USD and we need to tap this potential.

In Ethiopia, the existing knowledge of Renewable Energy Technology is limited. Consequently, we are facing several obstacles in implementing Renewable energy technologies high initial cost of some of the RET systems, insufficient number of experts in manufacturing such systems, and inadequate donor funding in renewable energy. In the world as whole funds for RET research are limited, government subsidies are gradually being withdrawn and the solar systems have to compete with the conventional systems. Manufacturers are facing great challenges. All this has forced the manufactures and the research scientists to achieve techno-economic viability of solar systems and make them compete with the conventional systems.

The development of RET will be significant if we can resolve issues such as strategic planning coherent national policymaking, economical and reliable technology, institutionalization of the technology transfer process, incentives such as tax credits, and subsidies, testing and certification facilities, motivation for investing in RET enterprises , and production of skilled personnel.

This paper deals with the cost of thermal energy collection with different solar thermal collectors for different temperature applications ranging from 30°C to 95°C.

COLLECTORS

Solar thermal collectors are basically heat exchangers that transfer the radiant energy of incident solar radiation to the sensible heat of the working fluid such as water and air. They are broadly classified as tracking and non-tracking type, a tracking collector follows the path of the sun thereby maximizing the effectiveness of incident radiation over its surface. Such collectors are more efficient and are used, in general, for thermal applications above 100°C. Non-tracking or flat plate collectors have a fixed position and are simple and need little maintenance. They are a good choice for temperatures below 100°C.

Non-tracking flat plate collectors are the simplest and the most commonly used solar appliances. They can be fabricated in a small factory with very little skill. Although their performance, cost design and materials of construction, differ, their salient components are collector. It is the heat exchanger that transfers the radiant energy to the sensible heat of the working fluid. It is generally made of metal such as copper, steel or aluminum. However, at present, low cost panels made of plastic material such as polypropylene are also gaining popularity for low temperature applications, e.g. swimming pool heating. Absorber panels are often painted black to maximize absorption of solar radiation. They can also be provided with selectively coated surfaces to maximize the short wavelength absorptive while minimizing long wave emissivity. Insulation and glazing are incorporated to improve the thermal energy collection efficiency of the solar collectors by minimizing the thermal losses.

For applications close to 100^{o}C, simple flat plate collectors are not suitable due to their high heat loss coefficient. For such applications, it is essential to minimize the heat loss coefficient in order to achieve reasonably good energy collection efficiency. One commonly used technique is to evacuate the space between the glazing and the absorber surface to cut down thermal losses. An evacuated glass tube with a central selectively coated absorber tubing is one of the most commonly used configurations. Such tube collectors have low convective and radiation losses, giving a high efficiency at temperatures near 100^{o}C.

APPLICATIONS

Thermal energy below 100^{o}C has very wide applications. Energy at this level is used in residential and commercial buildings to meet the water heating and space heating for agricultural and residency requirements. It has variety of applications in the industrial sector as well. Also, it can be used for production of cooling, fresh water and electricity. Some of the direct applications are hot water and space heating in the residential and commercial sector and in the chemical, primary metal, petroleum, coal production, paper, clay, glass and food processing industries. The important indirect applications include cooling, power and fresh water production.

In cold countries, the residential sector consumers a lot of energy for water heating and space heating. In the USA, space heating represents the largest energy usage in homes at 40%. The next two largest consumers are water heating at 17% and refrigeration at 9%. Residential air-conditioning accounts for an average of 7% of homes' energy use nationwide [1]. A similar scenario is likely to exist for other western countries. However, for hot tropical countries the situation is entirely different. Most of the densely populated nations are situated in the tropical zone. They have very little requirement of hot water heating or for space heating. Hot water in the industrial and commercial sectors represents a small but significant fraction of energy consumption. It is a very good match for solar thermal collectors. Equally good is the application of heating. It has a sizable contribution though it is limited only to cold countries. In the industrial sector, process heat accounts for nearly 50% of the total energy consumption and thus it is a good application.

Thermal energy below 100ºC can also be used to produce cooling (vapor absorption systems), fresh water (multi-stage flash desalination systems) or electricity (Ranking Power Systems). These indirect applications, except for electricity production, have optimum system involve additional hardware and thermodynamic process having a poor conversion efficiency. A techno-economic analysis for power, water and cooling production was made using solar and conventional energy source [2]. Prevailing techniques for water production or cooling using either electricity or a combination of electricity and thermal energy were analyzed. Both the stand-alone (fully dependent on solar energy) and the partial solar systems (thermal energy from solar energy and electricity and water from a conventional energy source) were analyzed. It was found that none of these techniques can compete with the conventional systems. The domestic solar water heater and a collector field for space heating are the two important systems for harnessing low grade thermal energy.

TECHNO-ECONOMIC ANALYSIS

Solar collector forms a major portion of the cost of the total solar energy system. The economic viability of any solar based technology or system is therefore dependent upon the economics of thermal energy collection by the collectors for any application (direct or indirect). It is therefore important to arrive at the technical and economic aspects of using alternative collectors for different applications.

The unit cost of thermal energy production has been considered as the single parameter to assess the techno-economic standing of a collector choice. It can be defined as the ratio of the amortized capital cost plus operation and maintenance (O&M) costs over the year and the total yearly production of the thermal energy by the energy by the system. For example, the unit thermal energy cost for a conventional oiler can be determined as follows [2]:

A. Capital Cost : Cost of the boiler
B. Amortization: Capital cost **X** Capital Recovery Factor (CRF)
C. O & M Cost : Operation cost + Maintenance Cost
D. Fuel Cost : Annual consumption of fuel in barrels (Birr/Barrels)
E. Unit Energy Cost : (B+C+D)/(Annual energy production; cents /$kWh_{th,}$ Where the h_{th} :: refers to thermal working hour

Figure 1 is a diagrammatic representation of the procedure adopted for the techno-economic analyses. The technical analysis gives the daily, monthly and yearly energy collection capability of a collector at a given temperature. The input for the economic assessment is the realistic cost estimate for the collector. The cost of thermal energy production in Birr/kWh_{th} is determined from capital investment, amortization parameters such as the life expectancy and the discount rate. A brief account of the technical and economic analyses is given below.

***Technical Analysis:* -** In the technical analysis, the thermal energy collection capacity of a collector is of prime interest. Important factors of analysis are the performance parameters of the collector such as the optical and thermal loss factor, the application of the solar system governing the temperature of the thermal energy collection and the location, controlling the availability of solar radiation and other environmental factors. The collector tilt is an important parameter for the flat plate collectors, as it can influence the availability of incident radiation over the collector surfaces and consequently the energy collection.

Four collectors with different constructional features and with thermal loss coefficients in the range of 2.0 to 12.5 $W/m^{2o}C$ have been taken as examples for technical analysis. Table 1 gives main technical data of these collectors.

Using the collector parameters and the weather data of, the hourly energy collection (Q) for a given collector is estimated using the following expression:

$$Q: I_{\tau\alpha} - U_L(t_w - t_a)$$

Where:

Q: hourly energy collection, Wh/m^2

I: monthly average, hourly radiation, Wh/m^2

$\tau\alpha$: Optical factor of the solar device

U_L: Heat loss coefficient, $W/m^{2o}C$

t_w: Energy collection temperature, ^oC

t_a: Ambient temperature, ^oC

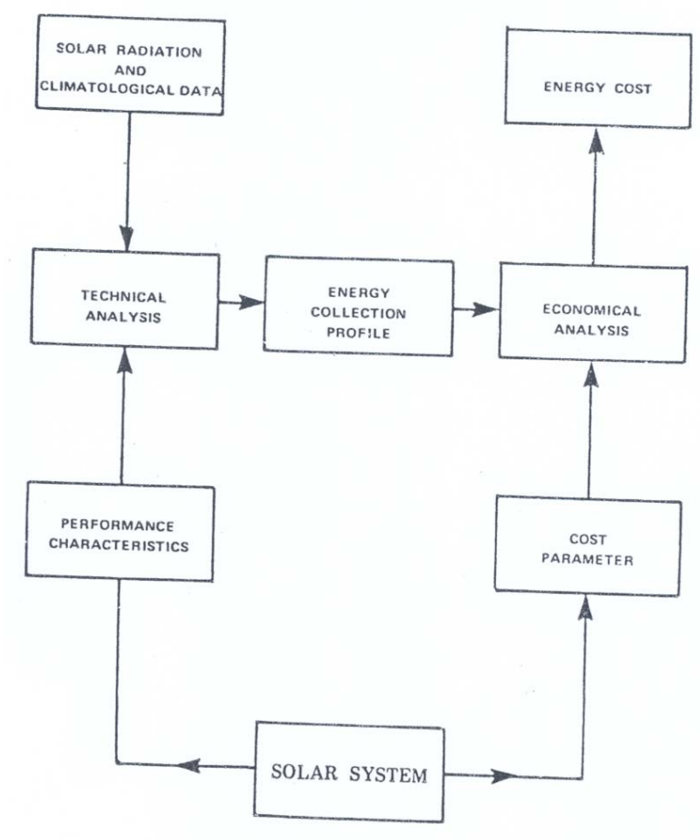

Fig.1 Assessment of methodology for solar thermal system

Table 1. Technical data of different collector [ ]

Solar device	**Collector**	**Collector**	**Collector**	**Collector**
Parameter	1	2	3	4
Country of origin	Jordan	Japan	West Germany	Japan
Make	Solar industries company	Hitachi	Soladur	NEG
Type	Flat plate	Flat plate	Flat plate	Evacuated tube
Box material	GI	Electroplated galvanized steel	NIL	Glass

Panel material	G.I. tube, steel sheet	Copper tube copper sheet	Polypropylene	Copper tube copper sheet
Type of surface coating	Ordinary paint	Ordinary paint	NIL	Selective coating
Optical factor ($\tau\alpha$)	0.748	0.748	0.850	0.900
	0.76	4.5	12-13	2.0
Thermal loss coefficient	1.18	2.01	1.8-6.0	0.227

The hourly average profile of energy collection given by Eq. 1, is used to estimate the monthly average daily energy collection, Q_{DJ} and the monthly energy collection, Q_{MJ}.

$$Q_{DJ} = \sum_{i=1}^{\theta} Q_i$$

$$Q_{MJ} = N_J(Q_{DJ})$$

where J refers to the month of the year, N the number of days in the month and θ the sunshine duration. Energy collection during the season or over the complete year is estimated by adding up the monthly energy collection given by the Eq. 3.

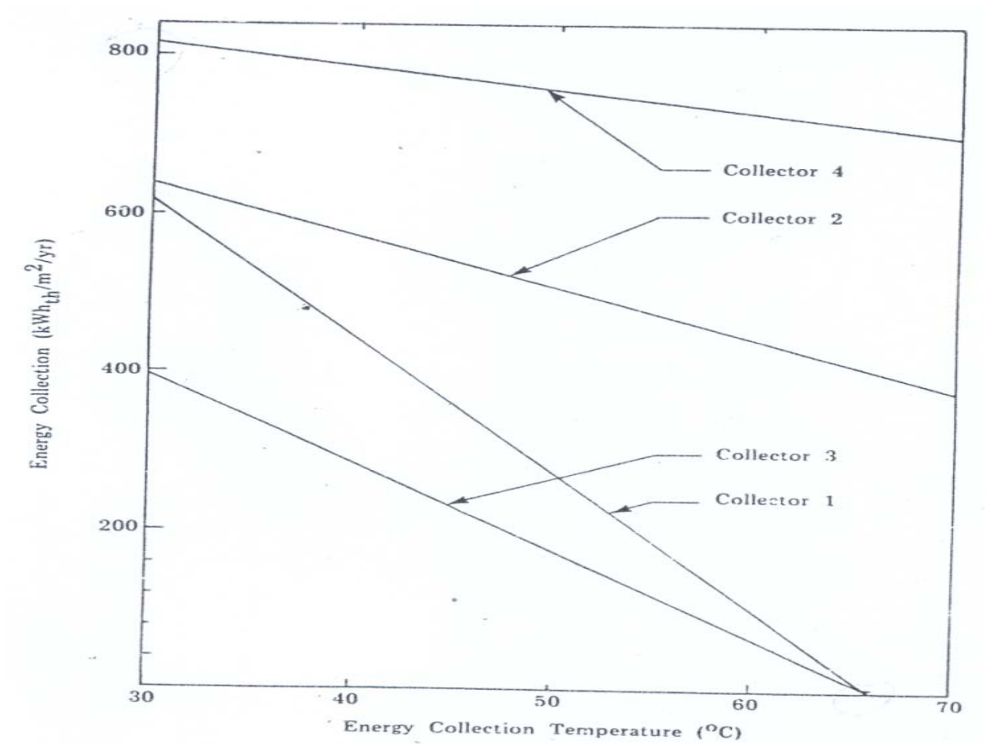

Fig2. Yearly energy collection-winter utilization.

Analysis has been carried out for different energy collection temperature in the range of 30 to 100°C for the following:

1. Collector tilt of 45°; winter season of six months,
2. Horizontal tilt; summer season of seven months,
3. Horizontal tilt; year round energy collection.

Figure 2 shows the thermal energy collection for each of the four collectors as a function of collection temperature for the winter season of 6months. Similar curves can be constructed for the other two cases.

Economic Analysis: The important economic data of a collector are its price in Ethiopia and the life-cycle in years. Prices of different collectors were estimated after accounting for the additional expenses of freight, insurance and the customs. The CRF of 0.147 for a life-cycle of 12 years and an annual discount rate of 10% was used to estimate the annual amortized cost per unit area of the collector. All these parameters are given in Table 2.

Table 2. Economic data of different collectors

Solar device parameter	**Collector 1**	**Collector 2**	**Collector 3**	**Collector 4**
Country of origin	Jordan	Japan	W-Germany	Japan
Quoted currency	US$*	y**	DM***	y**
Price FOB†/collector	132	NA	330	5640
Equivalent FOB cost in Birr	1623	NA	2316	476
Freight Insurance, customs, etc. as percentage of FOB cost %	15	25	25	25
Price in Birr/Panel	1845	-	2870	598.6
Panel size, m^2	1.18	2.01	6.0	0.227
Unit cost, Birr /m^2	1582.6	-	483.8	2619.9
Annual amortized cost, Birr /m^2/yr	232.47	-	71.34	384.99

Currency rates: *US$1 =13.63Birr, **y1 =3 fills 3 cents ***DM 1= 171 cents

+FOB =Free on Board (Cents & Birr) From Commercial Bank of Ethiopia Change

Techno-economic Viability of solar Collector: Using the results of the thermal energy collection and the annual amortized cost, shown in Table 2, the contribution of a collector towards the cost of thermal energy production can be estimated for different applications. The cost of thermal energy collection by different collectors as a function of energy collection temperature is shown in Fig.3 Table3 gives a list of some of the example applications along with the cost of energy collection with different collectors. The data shows that for the supply of hot water at 50^{o}C and below to the domestic and industry sectors, the unglazed polypropylene collector panel is the best choice.

Domestic hot water units (see Table 3) with unglazed plastic solar panels are competitive with conventional electrically operated geysers. The running cost of geysers or the cost of electricity production in Ethiopia is 41 cents/kWh_c.

For the solar hot water units, the contribution of collectors towards the cost of thermal energy production is 7.5 US cents /kWh_{th} (see Fig. 3). Assuming an equal cost for the balance of system, a domestic solar water heater can easily supply thermal energy at prices lower than the conventional system. Perhaps this is the only solar application which has economic viability at today's prices.

Fig 3. Cost of thermal energy production (collector contribution).

Numbers 1-4 refer to collectors of Table 1.

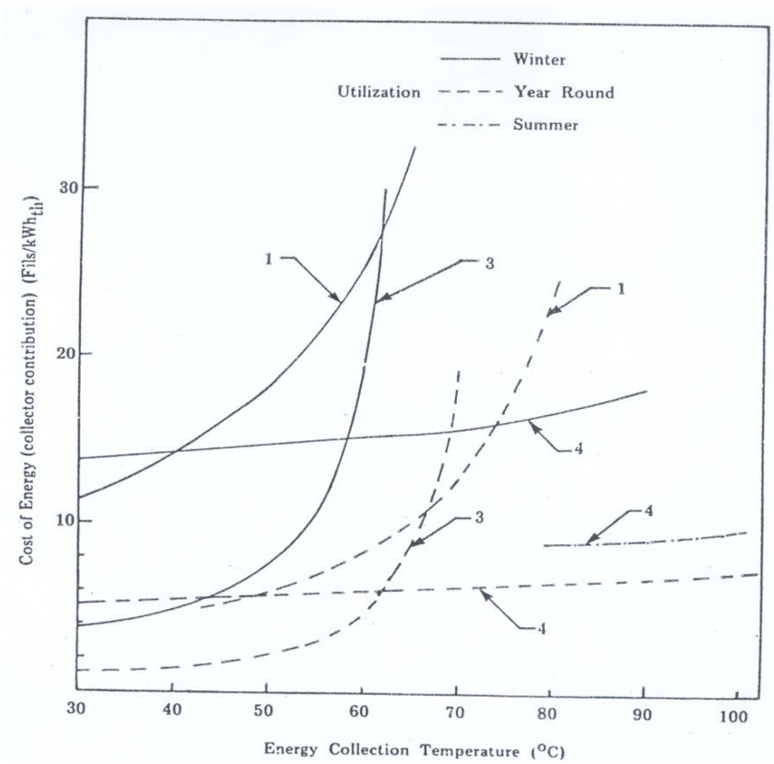

Fig.3 Cost of thermal energy production (collector contribution).

Numbers 1-4 refer to collectors of Table 1.

The techno-economic analysis can be easily extended to the total solar thermal energy collection system. This can be done by adding the cost of balance of systems to the collector cost and accounting for operation and maintenance and for the cost of energy spent by the pump motors in order to evaluate the cost of thermal energy production by the system.

Table 3 Techno-economics of some example applications.

Application (Temperature, °C)	Utility	Energy	(1) Cost	Energy	(2) Cost	Energy	(3) Cost	Energy	(4) Cost
		Energy collection for utility period (kWh) and unit cost of energy (cents /kWh)							
Domestic hot water (50)	Winter								
Swimming pool heating (50 °C)	Winter	309	18.4	423	NA	232	7.5	632	14.9
Space heating (50°C)	Winter								
Industrial hot water (50 °C)	Year	944	6.0	1163	NA	806	2.2	1644	5.7
Industrial process water (70 °C)	Year	438	12.9	840	NA	104	16.7	1499	6.3
Absorption cooling (90 °C)	Summer	51	111.2	464	NA	0	NA	1009	9.3
Rankine cycle power generation(90 °C)	Year	51	111.2	514	NA	0	NA	1354	6.9
Multistage flash water desalination (80 °C)	Year	237	23.9	677	NA	0	NA	1426	6.6

NA = Not Available

CONCLUSIONS

Domestic hot water and space heating is the only viable application of the solar energy at present. Serious efforts should, therefore, be made to maximize the use of such systems. Several small and large countries, both industrialized and non-industrialized, have already started to use domestic water heaters. Although, domestic water heating often represents less than 5% of the total energy consumption of a particular country and its scope is limited to certain countries, based on geographical location, successful implementation of these systems is of great importance. Industrial heating is another application which shows great promise for large scale applications.

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