# SOLAR WATER HEATING SYSTEMS DIFFUSION OPTIMIZATION ECONOMIC ANALYSIS: A CASE STUDY OF EGYPT

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## ABSTRACT

To meet its Electricity demand in 2030 Egypt has to introduce new renewable energy sources. Unfortunately, solar technologies' high initial cost is a barrier to its diffusion. The aim of this paper is to develop a model that studies the optimum use of funds to encourage the deployment of solar water heaters. Since Egypt has a high solar potential, the model is accustomed to the urban Residential sector in Cairo. The model uses optimization and the RETScreen Software. The model inputs include the percentage of subsidy, system's costs and electricity savings while the output is the minimum possible payback period.

## INTRODUCTION

The International Energy Agency (IEA) states that 47% of energy production in Egypt is consumed by the industrial sector, 20% by the residential sector, 29% by transportation, 2% by the agricultural sector and 2% by other sectors [Patlizianas, 2010] It is stated as well that the electricity generation is supposed to increase from 92 TWh in 2003 to 188 TWh in 2030 while the rate of energy demand in Egypt increases annually by 2.6% to be about 1267.67 TWh in 2030. In order to meet Egypt's electricity demand in 2030, it is highly recommended to introduce new renewable energy sources including solar, wind, hydro and biomass energy sources. According to the International Renewable Energy Agency IRENA [IRENA], the renewable energy represented about 3.8% of the primary energy supply in Egypt in 2008 while the target is to increase it to reach 14% in 2020. In order to achieve that target the Egyptian government has to seek alternative technologies that can replace conventional ones, spread the awareness among the public of their viability and encourage their adoption through policies and subsidy programs. One of the most common solar technologies nowadays is the solar water heating systems (SWH). It is claimed that about 30-40% of the energy consumption is used in water heating that is done by various types of fossil fuels consequently the use of solar water heating systems will reduce non renewable energy consumption as well as reducing the burden of energy production [Devabhatuni et al, 2012]. SWH have been available in the market since 1800s [Gastli et al, 2010] Nowadays, there are diverse types of solar water heaters in the market that vary in materials, lifetime, efficiency, design and cost [Reddy, 1994]. There are two main types of SWH namely, flat plate and evacuated tube. Solar Water Heating systems mainly consist of a collector and a storage tank. The performance of the SWH depends on a number of factors including the type of collector, area of the collector, efficiency, amount of solar radiation, required water temperature, slope and azimuth of the SWH [Gastli et al, 2010] Although SWH high initial cost is considered to be one of the main economic barriers that hinder its diffusion, they are more profitable than conventional water heaters on the long run thanks to its low maintenance costs, longer expected lifetime and electricity savings. Another advantage of SWH is that it reduces the carbon emissions that lead to global warming.

The aim of this paper is to study the economic feasibility of replacing conventional electric water heating systems by solar water heating systems through providing subsidies to the households. An optimization model has been developed to help decision makers who are willing to invest in the SWH market in Egypt to achieve the least possible payback period and maximize their profits. Section two is an overview of some of the policies and strategies implemented in other countries to encourage the deployment of SWH. Section three is an overview of the model and its parameters. Section four is the model formulas. Section five is a case study. Finally section six includes the conclusion and recommendations for future work.

## POLICIES TO SUPPORT SWH IN OTHER COUNTIRES

Recently, some governments have initiated incentive programs and policies to encourage the diffusion of solar water heating systems in their countries. The two main types of policies are subsidies and mandatory installation of SWH in new buildings. Table (1) is an overview of some of the SWH policies and subsidy programs in various countries. Soft loans are provided by the Indian government to the public users through a number of financial institutions in order to encourage the deployment of solar water heating systems. The loans' interest rates range between 2 and 5% according to the different categories of users and it is 0% for domestic users in certain states. Other policies in India include mandatory solar water heating systems installation in new buildings in addition to providing rebates in electricity bills to users of solar water heating systems [Veeraboina, 2011]. Cyprus suffers from a shortage in the natural resources required to satisfy its energy demands. In order to support energy conservation investments and the replacement of the conventional with renewable energy resources, the Cypriot government has provided grants that represent around 30% of the total costs. As a result, the rate of evacuated tube and flat-plate collectors installation in Cyprus is the highest in the world [Chang et al , 2010,Stevanovi et al, 2012]. Germany and Austria provide subsidies that reach half of the installation costs [Chang et al, 2010] China produces Solar Water Heating systems that are cheaper than western countries by about 80%. In addition to that the high efficiency of the evacuated tubes which allow the system to function in adverse weather conditions has lead to the popularity of Solar Water Heating systems in China and about 30 million households in China have installed one solar water heating system [Gastli et al, 2010]. In Greece 75% of the SWH investment costs can be deducted from the households' taxable incomes [Chang et al, 2010]. Spain was the second country to make the installation of solar water heating systems mandatory for new buildings in 2006 [Gastli et al, 2010]. The German government provided subsidies that range between 60 to 125 E/m2 between 1999 and 2010 [Stevanovi et al, 2012].]. The government grant is up to 50% in Kaohsiung in Taiwan and Basel in Switzerland [Stevanovi et al, 2012].]. The French government provides tax credits of about half the SWH installation costs [Chang et al, 2010]. The government of Taiwan has initiated two incentive programs. The first program was from 1986 to 1989 with a subsidy of 2000 NTD/m2 and 1000 NTD/m2 for glazed flat plate collectors and unglazed flat plate collectors respectively then the subsidy was reduced by 50%. This program resulted in the installation of 58000 solar water heating systems. The second program started in 2000 with a subsidy of 1500 NTD/m2 and 1000 NTD/m2 for glazed flat plate and evacuated tube solar collectors and unglazed flat plate collectors respectively [Chang et al, 2010].

## MODEL OVERVIEW

The Solar Water Heating systems deployment optimization model is a tool that guides decision makers and investors to the optimum usage of funds invested in the diffusion of SWH projects in order to maximize the profit and minimize the payback period. The user can be the Government, an investor or a venture capital. The model calculates the total amount of electricity saved consequently the total amount of money saved as a result of replacing the conventional electric water heating systems with solar water heating systems based on a number of inputs that the user defines over a period of time up to 10 years. The inputs of the model as will be further illustrated in the following sections include fund sum, targeted population, percentage of subsidy, adoption percentage, type of solar water heating system used, The amount of electricity saved per one SWH is calculated using RETScreen [10]. The output of the model is the project's least payback period that could be achieved. The variables of the model are the ratios between the amount of money paid to fund the project in the following year and the loan payment. The model can be customized to the use of other solar systems such as the photovoltaic systems.

Table (1)
SWH Adoption Policies

| Policy | Country | Amount |
|---|---|---|
| Soft Loans | India [4] | - |
| Mandatory in New Buildings | India [4] | N/A |
| | Spain [1] | |
| Subsidy | Germany (1999-2010) [2] | 60 to 125 E/m2 |
| | Austria [3] | Up to 50% of costs |
| | Taiwan [3] | Up to 50% |
| | Switzerland [2] | Up to 50% |
| Incentives | Taiwan (1986-1989) [3] | 2000 NTD/m2 |
| | Taiwan (1986-1989) [3] | 1000 NTD/m2 |
| | Taiwan (started in 2000) [3] | 1500 NTD/m2 |
| | Taiwan (Started in 2000) [3] | 1000 NTD/m2 |
| Tax Credits | France [3] | 50% of installation costs |
| | Greece [3] | Up to 75% |
| Grants | Cyprus [3,2] | 30% of total costs |
| Rebates in electricity bills | India [4] | - |
| Producing cheaper SWH | China [1] | by 80% |

## Model Parameters

### Fund

The amount of grant or fund invested in the project shall be determined by the user. The fund can be a loan from financial institutions or an investor's capital. The fund will cover the subsidized cost of SWH provided to the potential households including running costs such as operations and maintenance, taxes, customs and backup system.

### Targeted Population

The targeted population is the number of potential households that the user is targeting for the deployment of the SWH systems. They could be the residents of a small city or a whole governorate depending on the amount of fund the user is intending to invest.

### Subsidy Percentage

The subsidy percentage is the percentage of SWH initial and running costs subsidized to encourage the households to adopt solar systems and participate in the program. The subsidy percentage ranges between 0% and 100% depending on the user's target and the amount of fund available. If the user is the government then the main goal should be providing the service rather than making profits that's why the subsidy percentage is expected to be higher compared to the investor whose main goal is to maximize the profits.

### SWH adoption percentage

The SWH adoption percentage is based on the percentage of subsidy provided to support the adoption of the SWH. The user can either determine the adoption percentage or use the default percentage provided by the model. A survey has been conducted in order to determine the percentage of SWH adoption that corresponds to each subsidy percentage. The survey included general questions such as the number of occupants in the household, the household monthly income and the average daily water consumption.

### SWH Types Database

The user can select among the types of SWH systems included in the SWH database. The types include local and imported flat plate and Evacuated tube SWH. The database contains the initial costs of the systems, operation and maintenance costs as well as the percentage of the taxes and the customs added to the imported SWH. The increase in SWH initial and maintenance costs as a result of inflation is taken into considerations over the whole project duration.

### Electricity Tariff

The electricity tariff is measured in $/kwh. As the electricity tariff is highly subsidized in Egypt the user can insert the electricity tariff without subsidy. The following table shows the subsidized electricity tariff for the residential sector in Egypt. The tariff is measured in Egyptian Piasters/ kwh and it increases as the consumption increases, for example up till 50 kwh the tariff's cost is 5 piasters then the cost of the next 51 to 200 kwh is 11 piasters/ kwh.

Table (2)
Electricity Tariff

| Consumption KWH | Cost/KWH (Piasters/kwh) |
|---|---|
| <50 | 5 |
| 51-200 | 11 |
| 201-350 | 16 |
| 351-650 | 24 |
| 651-1000 | 39 |
| >1000 | 48 |

### Electricity Savings

The electricity savings per collector was estimated using RETScreen software [10]. The RETScreen [10] solar water heating project model is used for domestic hot water, indoor and outdoor swimming pools, and industrial heat processes applications in addition to commercial and institutional systems. It helps decision makers to estimate the applications' energy production, green house gas emission reductions and the life cycle costs.

### Optimization

The minimum payback period is the main output of the model as previously mentioned. The profits gained are calculated by deducting the total amount of costs including SWH systems initial, maintenance and operation costs from the total amount of electricity savings. The profits are divided into the amount of money that will be used to fund the project the following year and the amount of money that will be paid as payback of the loan. The percentages of the two divisions are considered the model variables. The constraints include that the variables have to be positive values and have to be less than 1 and that the cumulative loan payment should not exceed the amount of the loan after adding the interest rate.

**Model Formulas**

The cumulative number of installation over the 10 years can be calculated according to the following Equations

$$I_{yr\,1} = A * P \qquad (1)$$

$$I_{rem\,yr\,1} = P - I_{yr\,1} \qquad (2)$$

$$I_{rem\,yr\,2} = I_{rem\,yr\,1} - I_{yr\,2} \qquad (3)$$

$$I_{cum\,1} = I_{yr\,1} \qquad (4)$$

$$I_{cum\,2} = I_{cum\,1} + I_{yr\,2} \qquad (5)$$

The user selects the preferred type of SWH and the system's corresponding costs are included in the calculations taking into considerations the increase in costs due to inflation every year. The total cost per a solar water heating system is calculated according to the following formulas

Taxes and Customs are calculated as a 10% and 5% of the systems initial cost if applicable

$$T = 0.1 * IC \qquad (6)$$

$$C = 0.05 * IC \qquad (7)$$

$$TC = IC + OM + T + C \qquad (8)$$

The cumulative subsidized cost of collectors is calculated according to the following formulas

$$SC = TC * S \qquad (9)$$

$$TSC = SC * I\,(x) \qquad (10)$$

$$CSC = TSC\,(x1) + TSC\,(x2) \ldots etc \qquad (11)$$

The electricity saved per collector is an output of RETScreen [10] and the total amount of electricity saved can be calculated as follows

$$TES\,x = ES\,x * I\,x1 \qquad (12)$$

$$TES\,(cum) = TES\,x1 + TES\,x2 \ldots etc \qquad (13)$$

The cash flow in the first year can be estimated as follows

$$CF = F + TES - TSC \qquad (14)$$

As long as the cash flow is negative that means that the costs are more than the savings however once the cash flow value becomes positive that means that the project is making profits

The profits gained in each year shall be divided into two parts. The first part is to reinvest in the project for the following year and the second part is to pay the loan.

$$MF = CF * F\% \qquad (15)$$

$$ML = CF * L\% \qquad (16)$$

The amount of money used as a reinvestment in the project is deducted from the cost of the systems in the following year.

The payback period is calculated by summing values of the cash flow and the year where the first positive value appears is the considered the least payback period

## CASE STUDY

The case study is on the residential sector. The amount of power generated from solar technologies is highly dependent on the weather and the amount of solar radiation. Egypt is one of the countries that have a great potential to the implementation of solar technologies thanks to its weather and geographical location. The area selected for the study is Cairo.

The amount of fund used for the case study is a loan with a value of $ 2,000,000 and 4% interest rate while the number of households targeted is 1000,000.

The study considers 4 occupants in the household with daily hot water usage estimates of 220 L/day. The hot water temperature is 50 C while the operating days per week is 7 days. The type of solar water heating system selected for the study is Evacuated tube with an initial cost of $ 935 according to the local SWH market prices in Egypt. The total cost of the SWH system after adding taxes, customs and operation and maintenance costs is $ 1102

Table (3) shows RETScreen parameters used as inputs to estimate the value of electricity savings per collector. RETScreen has estimated the electricity savings per collector to be $ 141.

The project is a ten-year program where the investor provides a subsidy with a certain percentage of the total SWH costs to the resident while in return the resident pays the value of the electricity savings resulted from replacing the electric system with a solar system to the investor.

A survey was conducted to predict an acceptable subsidy percentage and the percentage of adoption corresponding to it. The survey included general questions about the number of occupants in the household, the average daily hot water consumption and the average monthly income as well as questions about the subsidy percentage that will encourage the resident to use SWH. The subsidy percentage and the percentage of adoption were chosen to be 50% and 50% respectively based on the survey results.

Table (3)
RETScreen Parameters

| Parameter | Value |
|---|---|
| Average number of people per house | 4 |
| Occupancy Rate (%) | 90 |
| Daily hot water usage estimate (L/day) | 220 |
| Hot water temperature C | 50 |
| Operating Days Per Week | 7 |
| Supply water minimum temperature C | 18.7 |
| Supply water maximum temperature C | 23.6 |
| Solar Water Heater type | Evacuated |
| Gross area per solar collector (m2) | 3 |
| Aperture area per solar collector (m2) | 2.8 |
| Fr (tau alpha) coefficient | 0.58 |
| Fr UL coefficient | 0.7 |
| Number of collectors | 1 |
| Capacity (Kw) | 1.96 |
| Initial Cost (US$) | 935 |
| Miscellaneous losses (%) | 3 |
| Storage capacity per square (L/m2) | 80 |
| Conventional fuel type | Electricity |
| Electricity Rate (US$) | 0.05 |
| Project life (Years) | 10 |
| Debt ratio (% of initial cost) | 0 |
| Initial Grant (% of initial cost ) | 10 |
| Annual O&M cost (US$) | 25 |
| GHG emission factor for natural gas (tCO2/MWh) | 0.467 |

The model variables defined are the percentage of money paid as an investment and the percentage of money paid for the loan. While the constraints of the optimization include that the percentages of investment and loan payment should be positive numbers and should not exceed 1. The set objective is to minimize the value of the payback period.

**Results**

The results have shown that the minimum payback period for the proposed scenario is 4 years. The cumulative cash flow shows that the investor will make profits of $ 3,530,548,110 after deducting the total loan payment from the total profits. It is assumed that all the profits are used as a fund for the following year.

It can be concluded from the results that it is preferable to pay back the loan payments as early as possible to avoid the annual increase of the interest rate. The results show that the loan is fully paid in the third year and the rest of the profits are reused to fund the project. Table (4) show summarizes the ratio between the percentage paid as fund and the percentage paid for the loan.

Table (4)
Fund to loan payment ratio

| yr | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| % Fund | 0.5 | 0.5 | 0.7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| % Loan | 0.5 | 0.5 | 0.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

The number of SWH installations according to the model was found to be 999023 systems.

## CONCLUSION AND RECOMMENDATIONS

To sum up, solar technologies can decrease the energy consumption and reduce global warming. Egypt is one of the countries that have a great potential for solar technologies such as solar water heating systems due to high rate of daily solar radiation and the geographical location however the high initial costs of solar technologies in general is a barrier that hinder its deployment. That's why, the Egyptian governments shall seek ways to encourage the citizens to replace their conventional systems by solar water heating systems through subsidy programs and grants. The model developed is a tool that helps decision makers optimize the profit and guide them to the optimum use of their investments. in the field of solar technologies. It can be used for other solar technologies such as photovoltaic cells. For future research, different interest rates for the loan payments shall be considered as well as calculating the electricity savings using electricity tariffs without subsidy.

## NAMENCLATURE

| | |
|---|---|
| $I_{yr\,1}$, | number of SWH installations in the first year; |
| $P$, | total Population determined by the user; |
| $A$, | adoption Percentage; |
| $I_{rem\,1}$, | number of installations left in the first year; |
| $I_{cum\,1}$, | cumulative number of installations in the first year; |

| | |
|---|---|
| $T$ , | taxes; |
| $C$, | customs; |
| $IC$, | initials cost of SWH system; |
| $TC$, | total cost of SWH system; |
| $OM$, | operation and maintenance costs; |
| $SC$, | subsidized cost per system; |
| $S$, | subsidy percentage; |
| TSC, | total subsidized cost; |
| $I_x$, | total number of installations in year x; |
| $TES_x$, | total electricity saved in year x; |
| $ES_x$, | electricity saved per collector in year x; |
| $TES_{cum}$, | cumulative amount of electricity saved; |
| $CF$, | cash flow; |
| $F$, | fund; |
| $MF$, | amount of money paid to reinvest in the project; |
| $ML$, | amount of money paid to the loan; |
| $F\%$, | percentage of money paid to reinvest in the project; |
| $L\%$, | percentage of Loan Payment; |

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