# Financial Modeling Tool of Solar Water Heaters for Domestic Hot Water (FiMo)

## In support for SHAMCI and NEEAP


RCREEE
Regional Center for Renewable Energy and Energy Efficiency
المركز الإقليمي للطاقة المتجددة وكفاءة الطاقة

# Contents

## 1 Rationale

One of the measures of the National Energy Efficiency Action Plans (NEEAPs) adopted by many Arab countries is to provide solar water heaters (SWHs) for heating domestic water. That would require basic financial assessment for obtaining SWHs on both the consumer level and the national level; and identify the key factors that affect the financial competitiveness and challenges of SWHs, such as energy prices and SWH systems prices.

Moreover, implementation of the SHAMCI certification nation-wide would involve a first-step evaluation of the impact of local manufacturing of SWH systems especially on the product price.

Therefore, a spread-sheet tool was developed for the following objectives:

- Give consumers an insight on the life cycle cost of obtaining a SWH system
- Assist policy makers in shaping SWHs national installation programs
- Reveal the factors affecting expected energy savings and monetary benefits, such as equipment prices and energy prices
- Highlight both financial benefits and energy savings
- Assist in shaping measures for the NEEAPs

## 2 Structure of the Modeling Tool

As Figure 1 indicates, the modeling tool is structured into two levels; the unit, or consumer, level and the national level. The unit level provides the life cycle cost savings and the payback period for obtaining a SWH system. The national level provides the monetary benefits, energy savings and installed capacity of a national installation program of SWH systems (Policy Analysis Modeling System).

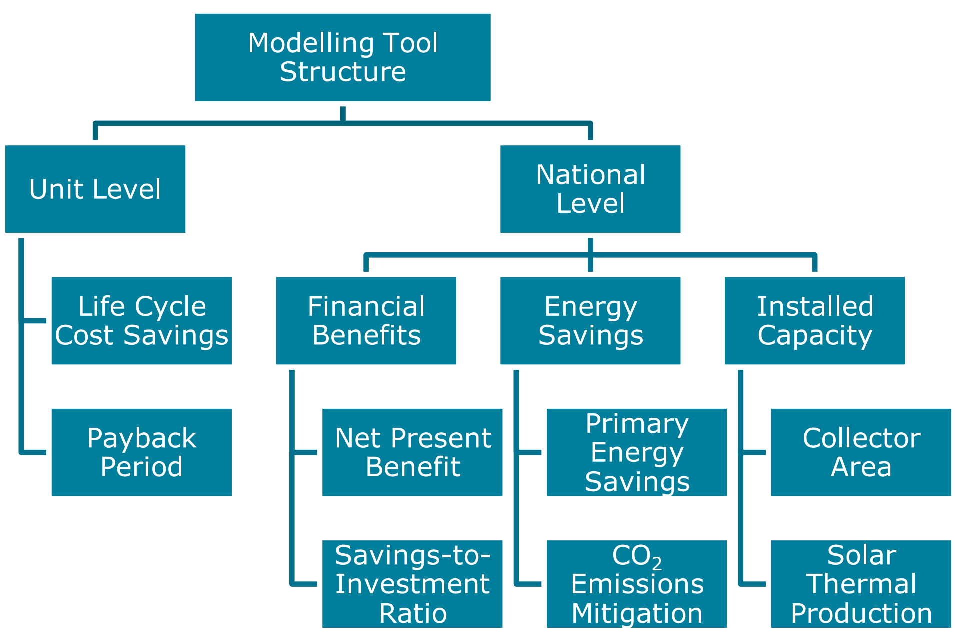


Figure 1: Modeling Tool Structure

There are two input fields in the tool; the first (unit level) input field and the second (national level) input field. The first input field consists of three sub-fields: "General", "Electric Water Heater" and "Solar Water Heater". The "General" sub-field contains the required daily hot water demand per person, water temperatures (cold and hot), electricity price, the consumer discount rate and the number of persons per household or building. The "Electric Water Heater" sub-field contains the price of an electric heater and its efficiency. The "Solar Water Heater" sub-field contains the solar global horizontal irradiation, expected lifetime of a SWH system, price of a SWH system per one $m^2$ of collector area, solar fraction and auxiliary power consumption for system components. The parameters provided in the first input field are sufficient to produce the unit level results. The unit level inputs and results are also shared with the national level calculations.

The second input field consists of three sub-fields. These sub-fields contain the required information for national installations of SWH systems. They include the start and end years of a national installation program; national discount rate; energy sector data, such as transmission and distribution losses factor and cost of electricity production; and the number of households to install or replace an electric heater with a SWH system.

# 3 Calculations Methodology

## 3.1 Unit Level

*Annual hot water energy load:*

$$Q = \frac{365 \times m \times C \times \Delta T \times n}{3600}$$

- Q: Annual energy load in kWh
- m: Daily average hot water demand per person in liters
- C: Water specific heat = 4.1813 kJ/kg*degree
- $\Delta T$: Water temperature difference in degrees
- n: Number of persons per dwelling

*For electric water heaters:*

Annual energy consumption for electric water heater:

$$E_{elec} = \frac{Q}{eff_{elec}}$$

- $E_{elec}$: Annual energy consumption in kWh
- $eff_{elec}$: Electric water heater efficiency in %

*For solar water heaters* (Solar Thermal Technology & Applications)*:*

$$A_c = \frac{Q}{eff_{system} \times H}$$

$$EQC_{SWH} = C_{solar} \times A_c$$

- $A_c$: Solar collector area in $m^2$
- $eff_{system}$: SWH system efficiency in %; including collector, storage and piping
- H: Average annual solar global horizontal irradiation (GHI) in $kWh/m^2$
- $C_{solar}$: Per-unit-area cost of installed SWH system in $Currency/m^2$
- $EQC_{SWH}$: Price of SWH system in Currency

*Annual energy consumption for a SWH system:*

$$E_{SWH} = Q(1 - SF) + Aux$$

$$Aux = 365 \times Auxiliary\ Rated\ Power\ (kW) \times Operation\ Hours\ per\ day\ (h)$$

- $E_{SWH}$: Annual energy consumption of a SWH unit in kWh
- SF: Solar fraction in %

Solar fraction is the amount of energy provided by solar energy divided by the total energy required. It depends on many factors such as load, collector and storage sizes, operation and climate conditions. The model assumes the backup heater is electric.

- Aux: Annual energy consumption of auxiliary components of a SWH system in kWh

*$CO_2$ emissions mitigation:*

$$CEM_1 = \frac{(E_{elec} - E_{SWH}) \times EF}{1 - TD}$$

- $CEM_1$: Annual $CO_2$ emissions mitigation of one SWH unit in kg
- EF: Emission factor in kg/kWh; amount of emissions released in kg per kWh of electricity generated
- TD: Electric power transmission and distribution losses in %

*Life cycle cost savings & payback period* (Policy Analysis Modeling System)*:*

$$LCC = EQC + \sum_{i=1}^{L} \frac{EC}{(1+R)^i}$$

$$EC = E \times P_{elec}$$

$$LCC\ savings = LCC_{elec} - LCC_{SWH}$$

$$PP = \frac{EQC_{SWH} - EQC_{elec}}{EC_{elec} - EC_{SWH}}$$

- LCC: Life cycle cost in Currency
- EQC: Equipment costs in Currency

Equipment costs include installation cost and, if applicable, present values of future maintenance costs. For an electric heater, the equipment cost is for the most available and/or cheapest product in the local market. For SWH, it is the average price of a SWH system available in the local market.

- EC: Annual energy costs in Currency
- PP: Payback period in years
- $P_{elec}$: Electricity price in Currency/kWh

Electricity price is the average price of 1 kWh paid by the consumer. The model assumes that electricity prices do not change over time.

- R: Consumer discount rate in %

Future costs are less important to consumers than near-term costs, so that future costs are divided by a discount factor. Consumer discount rates are parameterized according to the Human Development Index. The consumer discount rate could be the average interest rate for money that the consumer would use for paying the potential extra cost of a higher efficiency appliance such as a SWH. By default, discount rates are modeled according to current local interest rates (Policy Analysis Modeling System).

- L: Lifetime of the equipment

## 3.2 National Level

### 3.2.1 National Energy Savings

National energy savings (NES) is the difference in the national energy consumption (NE) between electrical heaters SWHs each year.

$$NES = NE_{elec} - NE_{SWH}$$

$$NE_{elec} = N \times E_{elec} \qquad\qquad NE_{SWH} = N \times E_{SWH}$$

- N: Annual number of SWH units to replace electric water heaters

#### 3.2.1.1 Primary Energy Savings (Policy Analysis Modeling System)

Unless there is a renewable energy share of total grid electricity generation, the model assumes that *all* electricity, which is consumed by electrical heaters and SWH systems, is generated from conventional energy sources (fossil fuel power stations).

$$PES = \frac{NES \times (1 - RE)}{(1 - TD) \times eff_{plant} \times 11630}$$

- PES: Primary energy savings in TOE $(1\,TOE = 41.87\,GJ = 11.63\,MWh)$
- NES: National energy savings in kWh
- RE: Renewable energy share of total on-grid electricity generation in %
- $eff_{plant}$: Efficiency of conventional thermal power plants in %

#### 3.2.1.2 CO2 Emissions Mitigation (Policy Analysis Modeling System)

$$CEM = \frac{NES \times EF}{1 - TD}$$

- CEM: $CO_2$ emissions mitigation in kg

### 3.2.2 Financial Benefits

#### 3.2.2.1 Net Present Value

It is the net financial benefit from implementing of a SWH replacement program to the nation as a whole. The calculation is parallel to LCC.

*For electric heaters:*

National Equipment Costs (NEQC) for electric heaters each year:

$$NEQC_{elec} = EQC_{elec} \times N_h$$

National Energy Costs (NEC) for electric heaters each year:

$$NEC_{elec} = NE_{elec} \times C_{elec}$$

- $C_{elec}$: Cost of electricity production in Currency/kWh

The cost of electricity production comprises generation and transmission costs to end-users.

*For solar water heaters:*

$$NEQC_{SWH} = EQC_{SWH} \times N_h$$

$$NEC_{SWH} = NE_{SWH} \times C_{elec}$$

Net National Savings (NNS) is the difference of equipment-costs-increase (ΔNEQC) and energy-costs-savings (ΔNEC) between electric heaters SWH systems each year.

$$NNS = \Delta NEQC + \Delta NEC$$

$$\Delta NEQC = NEQC_{elec} - NEQC_{SWH} \qquad \Delta NEC = NEC_{elec} - NEC_{SWH}$$

Net Present Value is defined as the sum over a particular forecast period of the net national savings in each year, divided by the appropriate national discount rate (Policy Analysis Modeling System).

$$NPV = \sum \frac{NNS}{(1+R_n)^{(Y-Y_0)}}$$

- NPV: Net present value in Currency
- $Y_0$: Analysis year, all costs and savings are present-valued to that year
- $R_n$: National discount rate in %

The national discount rate is used in evaluating national investments and may be taken from rates used in evaluating other programs, such as infrastructure improvement. It may also be based on the average cost of private capital, or it may be based on the social discount rate applied to government projects. A lower, social discount rate may be particularly relevant if the volatility of national energy supplies or costs hold the potential for creating economic or social crises (Policy Analysis Modeling System).

#### 3.2.2.2 Savings-to-Investment Ratio

It is the ratio of the present value savings to the present value costs of an energy conservation measure. The numerator of the ratio is the present value of net savings in energy. The denominator of the ratio is the present value of the net increase in investment.

$$SIR = -\sum \frac{\Delta NEC}{(1+R_n)^{(Y-Y_0)}} \Big/ \sum \frac{\Delta NEQC}{(1+R_n)^{(Y-Y_0)}}$$

- SIR: Savings-to-investment ratio, if SIR > 1, then the project is cost effective

### 3.2.3 Solar Collector Energy Output

It is advisable by the International Energy Agency - Solar Heating & Cooling Programme (IEA-SHC) to present the installed capacity of SWHs not only in $m^2$ but also in $kWh_{th}$ and $KW_{th}$ in order to compare solar thermal contribution with other energy produced using different energy sources.

The following expressions give only an estimate of the annual solar energy output. The level of uncertainty introduced by using these expressions is not negligible, therefore they should only be used when no other detailed methods exists. The equation could be used by countries which have no detailed method or procedure for determining the annual energy output of solar thermal systems (Common Calculation Method: Solar Collector Energy Output).

For glazed collectors used for domestic hot water production,

$$Q_t = 0.44 \times H \times A_c$$

- $Q_t$: Annual solar thermal collector output in $kWh_{th}$
- H: Annual global solar irradiation on horizontal in $kWh/m^2$
- $A_c$: Collector aperture area in $m^2$

$$P = 0.7 \times A_c$$

- P: Solar thermal collector output in $kW_{th}$

## 4 Limitations of the Modeling Tool

There are some aspects which are not fully considered or covered in the modeling tool. These aspects are mentioned in the following paragraphs.

Electricity prices and electricity production costs do not change over time. It is very difficult to analytically predict and simulate the future changes in electricity prices and the fluctuations in electricity production costs due to the unpredictable changes in fossil fuel prices.

Only energy costs are considered as running costs. There are costs that are not included in the life cycle cost analysis, such as maintenance costs. That could be overcome by adding the present value of future maintenance costs to the equipment purchase price.

# 5 Works Cited

*Common Calculation Method: Solar Collector Energy Output.* (n.d.). Retrieved June 2013, from International Energy Agency - Solar Heating & Cooling Program: http://www.iea-shc.org/Data/Sites/1/documents/statistics/Calculation_Method.pdf

*Policy Analysis Modeling System.* (n.d.). Retrieved April 2013, from CLASP: http://www.clasponline.org/Tools/Tools/~/media/Files/PAMS/PAMSMethodology.pdf

*Solar Thermal Technology & Applications.* (n.d.). Retrieved April 2013, from Global Solar Thermal Energy Council: http://apps1.eere.energy.gov/tribalenergy/pdfs/course_solar_taylor_thermal.pdf