

FRAUNHOFER-INSTITUTE FOR SOLAR ENERGY SYSTEMS

# **SOLAR HEAT IN INDUSTRIAL PROCESSES - FEASIBILITY CALCULATOR FOR MEXICO**

User Manual

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# 1 Introduction

The total energy demand of worldwide thermal industrial processes is higher than the overall electricity demand (IEA - International Energy Agency, 2013). Solar process heat systems are one measure to reduce the carbon footprint in this sector significantly.

The implementation of solar collectors in process heat systems is in many cases a very interesting option to produce heat, not only from a technical and environmental, but also economical point of view. Still, there are several doubts and hurdles during the decision making process. One difficulty is definitely the expectation of low payback periods of new investments that solar systems usually cannot provide. However, solar installations provide safety of energy supply along the life time of the solar system of about 20 years and allow independence on the volatility of the fossil fuel prices. For solar systems, heat production costs can be estimated very accurately in contrast to fossil fueled heat production costs. Investments may bring additional intangible benefits for the company.

The techno-economic analysis is one of the most important aspect in each feasibility study. In the course of the project TrustCS, a excel tool was developed that supports detailed pre-feasibility calculations. This user manual describes the usage of the "Solar Heat for Industrial Processes (SHIP) - Feasibility Calculator for Mexico".

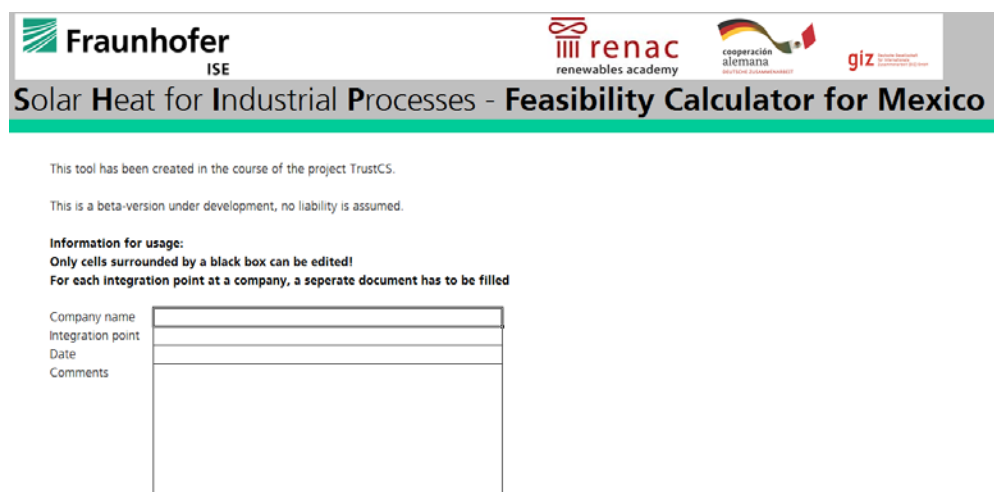
The latest version of the tools is:  
20190301\_SHIP\_Feasibility\_Calculator.xlsx

## 2 User Instructions

The excel tool is separated in seven separate tabs that deal with consecutive steps of a feasibility study. The order of the tabs should not be changed.

### 2.1 General usage information

The start sheet gives general information of the tool, like the version name and general usage information (Figure 1). It is indicated that in the following sheets only cells that are surrounded by a black box can be filled. If there is several options for integration points in a company, a separate copy of the document has to be used. For later reference, the company name, integration point date and other comments can be noted in this first sheet of the excel tool. These inputs will not have an effect on the following calculations.



**Figure 1: Start sheet**

### 2.2 Sheet “Energy Demand”

The sheet “Energy Demand” gives information on the load profile of the company (Figure 2). The annual heat demand, the number of annual operation days, the daily and weekly schedule, the type of boiler/process, steam/hot water temperature as well as pressure level needs to be given. In the following some additional information is given for each input and calculated values.

#### Annual heat production:

This is the annual heat production, of the process that is supposed to be substituted with solar heat. If solar integration at supply level is targeted, this may be equal to the overall annual thermal energy consumption. In case of targeted integration at process level, it is the annual heat demand of this single process only.

#### Annual schedule:

The number of annual operation days. This includes weekends, holidays, and seasonal shut downs.

Daily schedule:

Two schedules are available: Daytime operation between 8 am and 8pm as well as continuous operation all day. The schedule closest to the process schedule should be selected.

Weekly schedule:

Two schedules are available: 5 day/week operation and 7 day/week operation. The schedule closest to the process schedule should be selected.

Type of boiler or process:

Two types are available: Steam and hot water.

Steam/Hot Water temperature (boiler outlet):

Four temperature levels are available: 50, 100, 150 and 200 °C. The feed water temperature is always assumed to be 30 K lower than the operation temperature.

Pressure level:

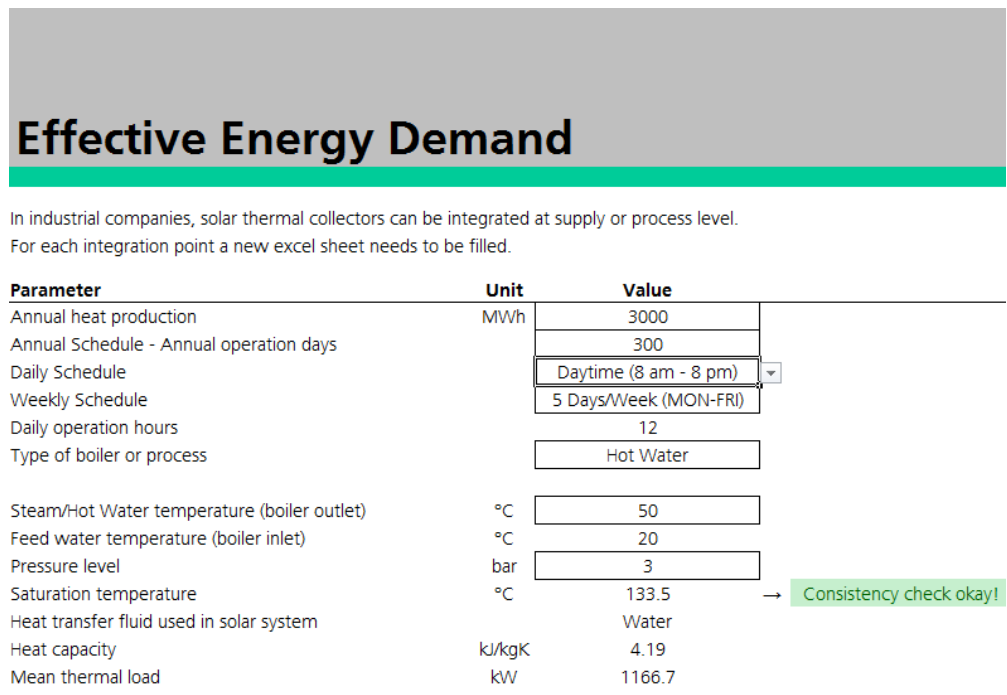
The pressure level is used to perform a consistency check of the previously given information. The saturation temperature is calculated with this pressure. If steam was selected before, the saturation temperature should be below the operating temperature. If hot water was selected before, the saturation temperature should be above the operating temperature.

Heat transfer fluid used in solar system and heat capacity:

The recommended heat transfer fluid for solar systems that produce steam is thermal oil. If hot water is produced, the heat transfer fluid is water. The heat capacity is given.

Mean thermal load:

The mean thermal load during one operation day is calculated.



**Figure 2: Sheet "Energy Demand"**

## 2.3 Sheet “Available Area”

In this sheet, the available free space for the installation of solar thermal collectors is given (Figure 3). Sufficient load resistance, good accessibility, connection to water and electricity supply as well as little or no shading (due to plants and buildings) should be guaranteed for the given space. Additionally, the distance to the integration point should be as short as possible. The orientation for surfaces with tilt angle should ideally be south/west for northern hemisphere and north/west for southern hemisphere.



In this table, the available free space for the installation of solar thermal collectors is given.

Parameter	Unit	Value
Available free space	m <sup>2</sup>	4000

**Figure 3: Sheet “Available Area”**

## 2.4 Sheet “Solar Energy Yield”

The sheet “Solar Energy Yield” calculates the potential solar yield for the previously specified integration point (Figure 4). The annual direct normal irradiation (DNI), annual global horizontal irradiation (GHI), collector technology targeted solar fraction, and storage size need to be given. In the following some additional information is given for each input and calculated values.

### Annual Direct Normal Irradiation (DNI) at project site & Annual Global Horizontal Irradiation (GHI) at project site:

The irradiation data for the project site can be extracted from the publically available website <https://globalsolaratlas.info>. For a given site, the annual irradiation values are given and shown on a map.

### Collector technology:

Four collector technologies are available: Flat Plate, Evacuated Tube, Parabolic Trough and Linear Fresnel collectors can be selected. Typical collector parameters are used for the further assessment. A consistency check is performed to check, if the technology is suitable for the given operation temperature.

### Targeted solar fraction:

Three solar fractions are available 30, 40 and 50 %. This value indicates what fraction of the heat demand is supposed to be substituted with solar heat. Usually solar fractions between 30 and 50 % lead to the most economically and environmentally interesting results.

### Specific storage size:

Four sizes of storage tanks can be selected: “Very small” or 300 Wh/m<sup>2</sup> of solar field area, “Small” or 700 Wh/m<sup>2</sup> of solar field area, “Medium” or 1100 Wh/m<sup>2</sup> of solar field area, “Large” or 1500 Wh/m<sup>2</sup> of solar field area. Based on this and the previously given heat transfer fluid, the specific storage capacity and volume is calculated.

System efficiency:

System efficiency is calculated based on technology, solar fraction and storage size. This efficiency is calculated based on roughly 10'000 simulations that were performed for several locations in Mexico with different load and operation inputs.

Solar field area:

The solar field area is calculated with the irradiation data, system efficiency and energy demand. A consistency check is performed to see, if the available are is sufficient for the installation of the given collectors. The factor to calculate required space from aperture area for the different collector technologies is:

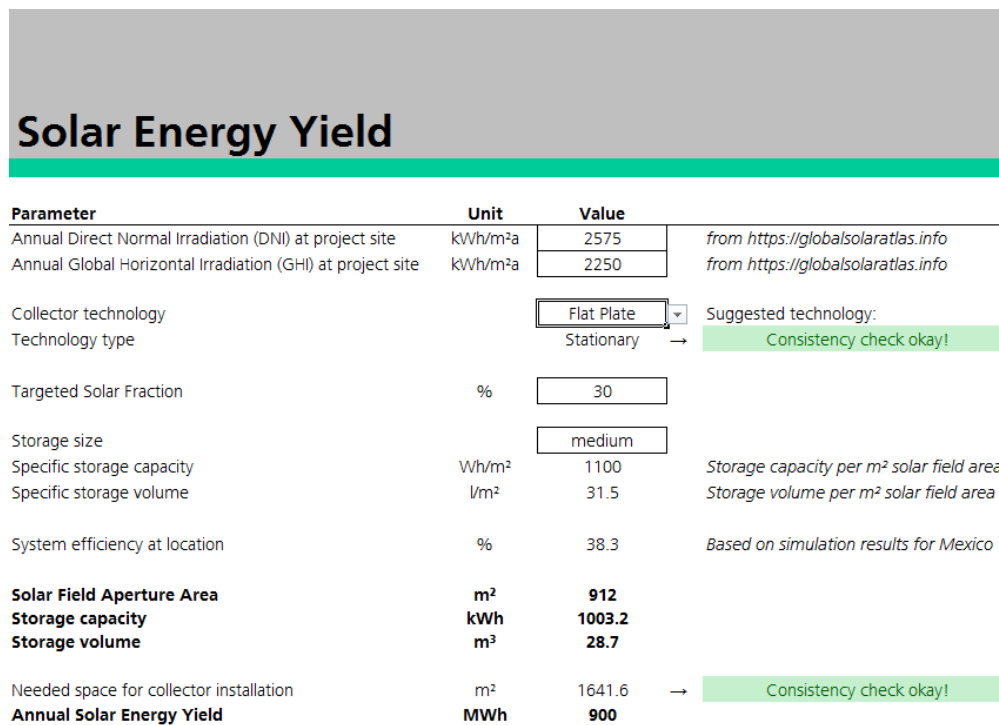
Collector technology	Factor required space/aperture area
Flat Plate	1.8
Evacuated Tube	1.8
Parabolic Trough	2.5
Linear Fresnel	1.6

Storage size:

Absolute storage size (capacity and volume) is calculated based on aperture area and specific storage size.

Annual solar energy yield

Annual solar energy yield is calculated based on the energy demand and targeted solar fraction.



**Figure 4: Sheet "Solar Energy Yield"**



## 2.5 Sheet “Plant Cost”

The sheet “Plant Cost” calculates the capital costs (CAPEX) and operational costs (OPEX) of a project (Figure 5). The specific collector and storage costs, other costs and operational expenditures need to be given. In the following some additional information is given for each input and calculated values.

### Specific collector costs & Specific storage costs

The collector and storage costs can be given as specific values in US\$/m<sup>2</sup> and US\$/m<sup>3</sup> as usually the exact cost are not known in the pre-feasibility phase.

### Absolute collector costs & Absolute storage costs

Absolute costs are calculated. The specific value is multiplied with the previously given plant dimensions (Sheet “Solar Energy Yield”).

### Other costs

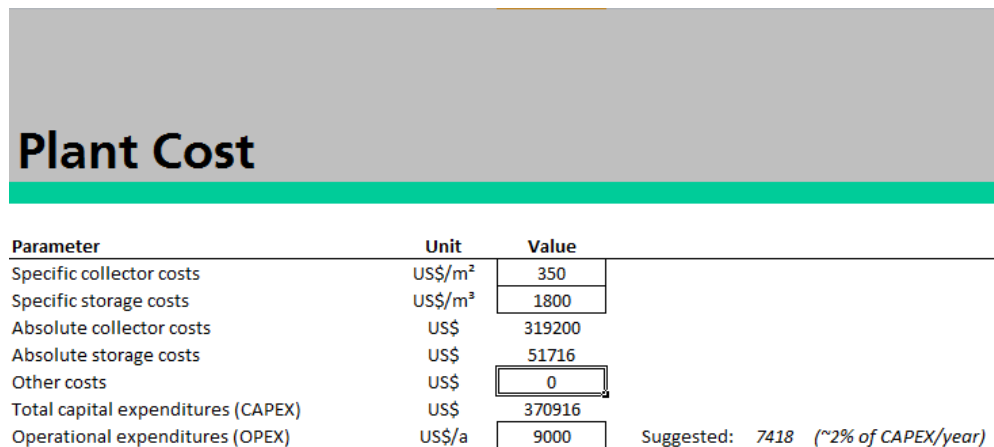
The previously given costs may not include additional costs for engineering, piping, monitoring equipment etc. These additional costs can be given here.

### Total capital expenditures (CAPEX)

The sum of collector, storage and other costs

### Operational expenditures (OPEX)

Operational costs in US\$/a. If this is not known, a suggested value is given in the cell right of the input cell. The suggested value is equal to 2 % of the overall CAPEX.



Parameter	Unit	Value
Specific collector costs	US\$/m <sup>2</sup>	350
Specific storage costs	US\$/m <sup>3</sup>	1800
Absolute collector costs	US\$	319200
Absolute storage costs	US\$	51716
Other costs	US\$	0
Total capital expenditures (CAPEX)	US\$	370916
Operational expenditures (OPEX)	US\$/a	9000

Suggested: 7418 (~2% of CAPEX/year)

**Figure 5: Sheet “Plant Cost”**

## 2.6 Sheet “Economic Feasibility”

The sheet “Economic Feasibility” calculates the project margin, discounted payback period, simple payback period and Levelized cost Heat (LCOH) (Figure 7). Comparative energy costs, project life time, inflation rate and effective cost of capital (COC) rate need to be given. In the following some additional information is given for each input and calculated values.

Annual Yield, CAPEX and operational expenditures are extracted from the previous sheets and explained in the according chapters of this user manual.

Conventional/Comparative Heat/Energy Costs (CHC)

Average energy cost in US\$/MWh of the fuel that is currently (first year of operation of the plant) used in the company. High conventional energy costs will improve the solar financial assessment.

Project lifetime

Plant life time for financial calculation of discounted cash flows (for solar thermal plants 20 years is the usual project lifetime).

Inflation rate

Average inflation rate at project location for period of project lifetime. High inflation rate will improve the solar financial assessment as energy costs will increase.

Weighted average cost of capital (WACC)

Calculated from debt ratio, cost of debt and equity: requires inputs of debt and equity rate (which are optional inputs). WACC must be lower than the effective rate/cost of capital (COC). A consistency check is performed to make sure this is the case.

Cost of capital rate (COC) – given and implied

Effective rate of cost of capital (COC). This value needs to be higher than the Weighted average cost of capital (WACC). A consistency checks is performed to make sure WACC is lower than COC.

Effective rate adjusted for inflation

COC adjusted for inflation

Free cash from saved costs

Yearly saved costs from energy savings minus operational costs (free cash flow)

Annuity factor based on inflation-adj. COC

Sum of annual discount factors

**Following parameter (project market value, project margin, ROI, payback period and LCOH) are feasibility parameters that indicate the success of the feasibility assessment; most important: if the project margin is above zero, the project is economically viable.**

Project market value based on given COC-rate

Market value/selling price calculated as free cash flow times annuity factor

Project margin (NPV – net present value)

Project is feasible if NPV is positive as its possible to gain profits with the project

Project return on investment (ROI)

IRR of saved costs on CAPEX – ROI need to be higher than COC to reach positive NPV

Simple and discounted payback period for CAPEX

Years required to pay back the invested CAPEX excl. costs of capital (simple) or including costs of capital (discounted)

LCOH (levelized costs of heat)

Costs of heat provide by solar thermal plant during project life time, either initial costs inflating over lifetime (starting price) or average costs constant over lifetime (average price)

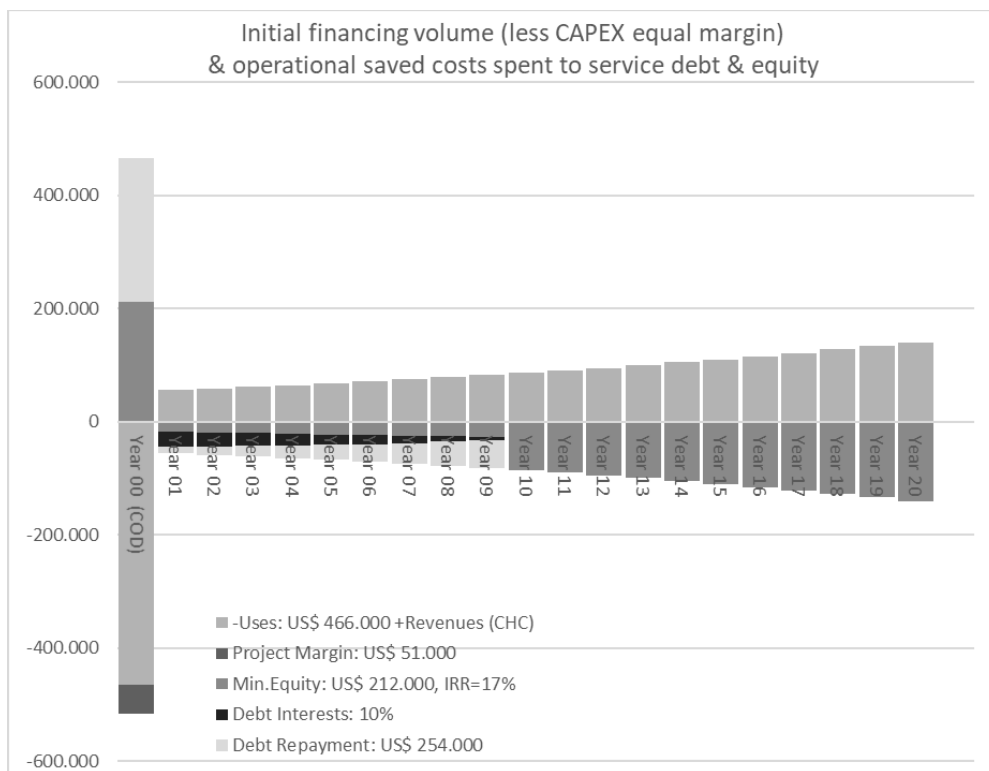
Optional consistency checks

Based on additional inputs "Offtaker's debt ratio =debt/(debt+equity)", "Offtaker's required rate on equity", "Bank's offer of debt tenor", "Bank's offer of client debt/interest rate", "Bank's offer of debt service coverage ratio" and previous input parameters.

With these parameter, the user can gain further results like debt volume based on bank's market offer and oftaker's debt ratio as well as required equity based on oftaker's equity rate. Additionally, the return on equity (IRR) is calculated.

Graphic

Shows cash flows of initial financing volume less CAPEX equal margin vs operational saved costs spent to service on dept & equity. Additionally, the main key figures of the project are given (CAPEX, project margin, debt and equity, IRR and interest rate).



**Figure 6: Evaluation graph "Economic Feasibility"**

## Economic Feasibility

Parameter	Unit	Value	Comment
Annual yield	MWh	1.200	Extracted from tab "Solar Energy Yield"
CAPEX or investment	US \$	466.000	Extracted from tab "Cost Data"
Operational expenditures	US \$/a	7.000	Extracted from tab "Cost Data"
Conventional/comparative heat/energy costs CHC	US \$/MWh	50	price per MWh usually above 30 US \$/MWh
Project lifetime	a	20	usually between 5 to 20 years
Inflation rate	%/a	5,0	<b>Inflation usually above 2 percent (select country)</b>
Weighted Average Cost of Capital (WACC)	%/a	12,5	calculated as: (debt rate% x debt ratio%)+(equity rate% x (1-debt ratio%))
COC (given): Cost Of Capital-rate	%/a	13,5	→ <b>Consistency check okay!</b> WACC below COC.
COC (implied): rate based on equity- & debt-rate	%/a	13,6	→ <b>Consistency check okay!</b> Inputs: COC-, debt-, equity-rate consistent
Effective rate adjusted for inflation	%/a	8,1	COC adjusted for inflation = (1+COC%)/(1+inflation%)-1
Free cash from saved costs	US \$/a	53.000	annual yield times saved heat costs less operational expenditures
Annuity factor based on inflation-adj. COC	-	9,7	Sum of annual discount factors = (1-(1+rate%)^-time)/rate%
<b>Project market value based on given COC-rate</b>	<b>US \$</b>	<b>517.000</b>	calculated as: Free cash times annuity factor
<b>Project margin = Market value - CAPEX = NPV</b>	<b>US \$</b>	<b>51.000</b>	→ <b>Project is economically viable!</b> Positive project margin: NPV>0!
<b>Project return on investment (ROI)</b>	<b>%</b>	<b>15</b>	IRR of saved costs on CAPEX Project return > COC => Margin >0!
<b>Simple payback period for CAPEX excl. COC</b>	<b>years</b>	<b>7</b>	period when sum of project cashflows equal investment
Discounted payback period for CAPEX incl. COC	years	16	payback period including interests of effective rate (informative)
LCOH (initial cost inflating over lifetime)	US \$/MWh	46	starting price increasing at inflation over life time
LCOH (average cost constant over lifetime)	US \$/MWh	63	flat price paid constantly over project life time (informative)
<i>Assessment based on capital market prices/offers</i>			
Offtaker's debt ratio (=debt/capital)	%	Optional 50	Indication 50 usually ranges from 30 to 70 percent (corporate finance related)
Offtaker's required rate on equity (market price)	%/a	15,0	<b>equity rate (above lender's client rate)</b>
Bank's offer: Debt tenor	years	9	usually ranges from 5 to 15 years
Bank's offer: Client debt-rate (market price)	%/a	10,0	<b>lending rate +incl. client risk premium (select country)</b>
Bank's offer: Debt service coverage ratio (DSCR)	%	150	usually ranges from 120 to 200 (project finance related)
<b>1. Debt volume based on bank's market offer</b>	<b>US \$</b>	<b>254.000</b>	should compare to debt ratio based volume
<b>2. Debt volume based on offtaker's debt ratio</b>	<b>US \$</b>	<b>258.500</b>	should compare to market offer (informative)
<b>1) Equity vol. based on offtaker's equity-rate</b>	<b>US \$</b>	<b>259.000</b>	equity volumes should compare
<b>2) Residual Equity vol. to match Project market value</b>	<b>US \$</b>	<b>263.000</b>	equity volumes should compare (informative)
<b>3) Min. Equity vol. to cover CAPEX (informative)</b>	<b>US \$</b>	<b>212.000</b>	equity as CAPEX less debt based on bank-offer (informative)
Return on equity based on min. equity & bank-offer	%/a	17	equity return on min. equity at debt of bank-offer

Figure 7: Sheet "Economic Feasibility"

## 2.7 Sheet "Environmental Impact"

In sheet "Environmental Impact" the saved greenhouse gas (GHG) emissions are calculated (Figure 8). In the following some additional information is given for each input and calculated values.

### Conversion efficiency

Efficiency of conventional energy system to calculate primary energy consumption.

### Fuel

Five different fuel types can be selected: Natural gas, diesel, coal, wood or electricity. If the type "User defined" is selected, the GHG emissions in g/kWh can be given as an input. If one of the five fuel types is selected, the emissions are extracted from a data base.

### Saved GHG emissions

The saved GHG emissions are calculated based on the fuel and annual solar energy yield. The higher the emissions, the higher the environmental benefit.

## Environmental Impact

Parameter	Unit	Value	Comment
Annual Solar Yield	KWh/a	900.0	Extracted from tab "Solar Energy Yield", equivalent to saved energy
Conversion efficiency	%	0.8	For conventional energy system
Fuel		Natural gas	
GHG emissions	g <sub>CO2</sub> /kWh	202	
GHG emissions	g <sub>CO2</sub> /kWh	0	(is only used, if "User defined" is selected in cell "Fuel")
Saved GHG emissions	kg <sub>CO2</sub> /a	227.3	

Figure 8: Sheet "Environmental Impact"