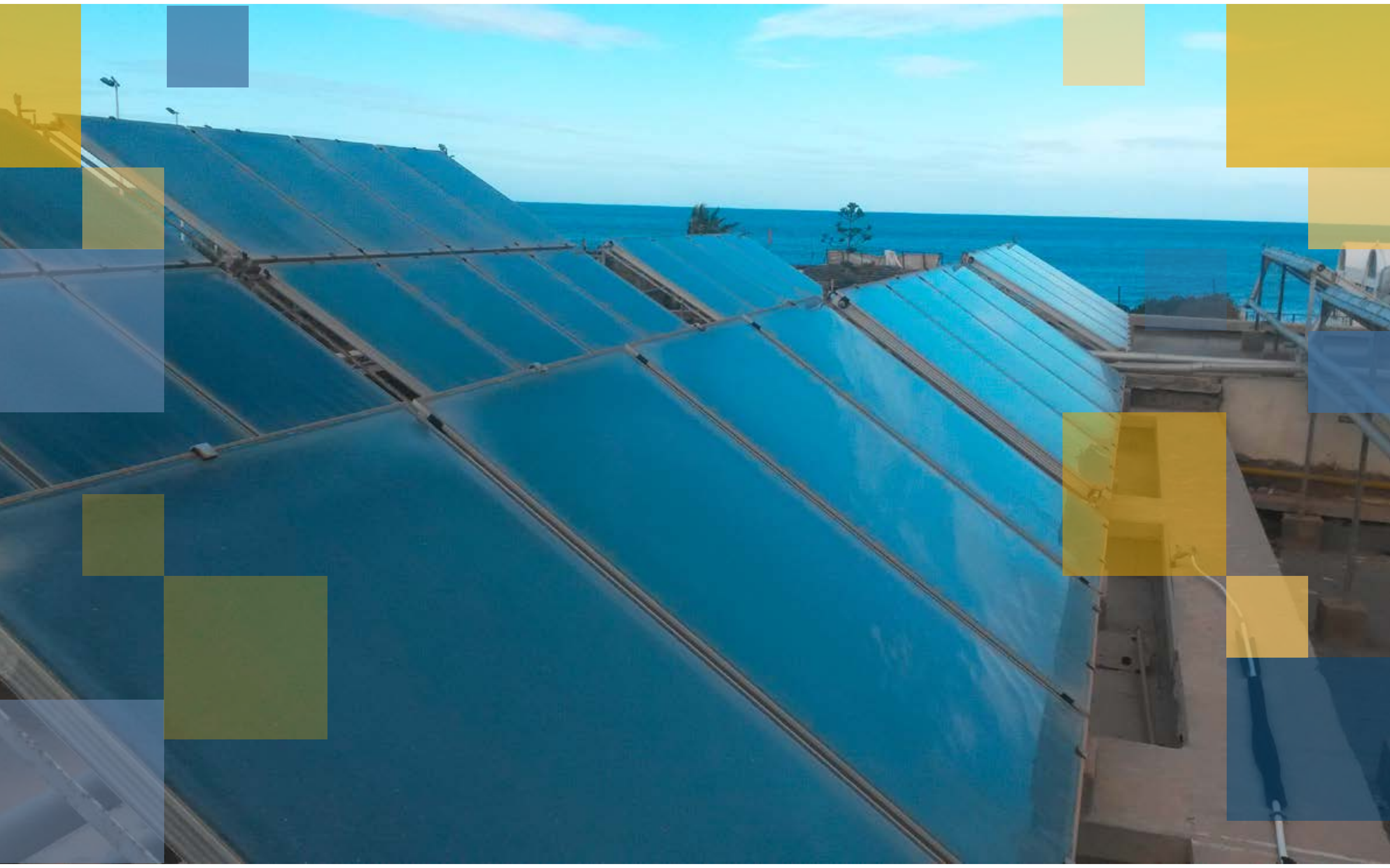

Opportunities for solar thermal systems in the tertiary and industrial sectors in Tunisia

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Abstract

The study "Opportunities for solar thermal systems in the tertiary and industrial sectors in Tunisia" analyzes the technical and economic potential of solar thermal applications on the basis of individual case studies. By examining typical heat consumer profiles in Tunisia, the analysis compares three different solar thermal technologies that can be used to replace conventional heat supply technologies and lead to fossil fuel savings. Simulations for different geographical locations are compiled and then compared to economic boundary conditions. A comprehensive sensitivity analysis enables the evaluation of the effect of changes in framework conditions (such as changes in subsidy, technology costs, fuel prices) on the profitability of solar thermal systems. The study gives an overview of present market segments and provides guidance with regard to the economic feasibility of respective systems. The study draws conclusions for policymakers that are aimed at unlocking further market development potential.

Content

1. Executive summary

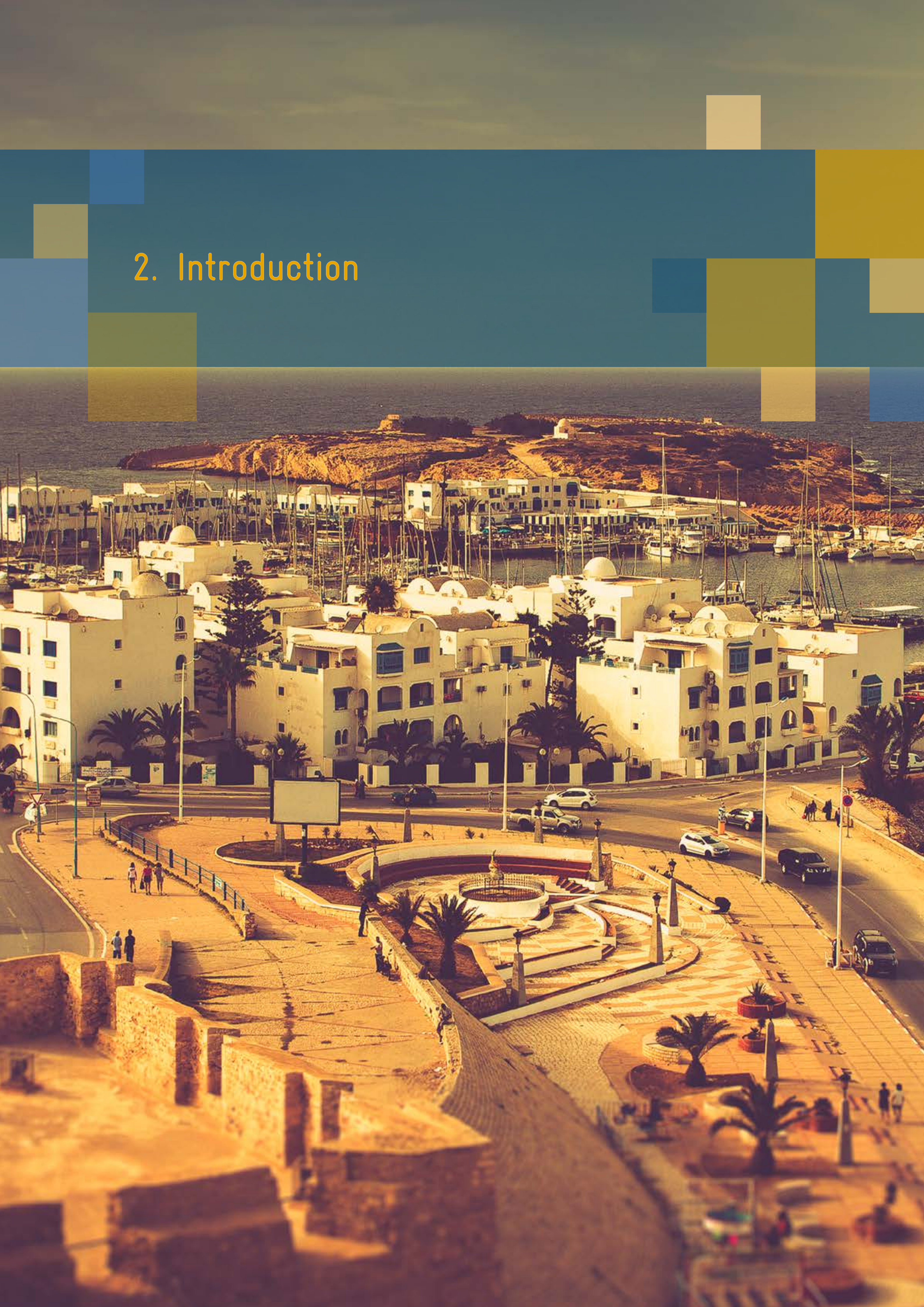
Foto: Marques / Shutterstock.com

The study "Opportunities for solar thermal systems in the tertiary and industrial sector in Tunisia" analyzes the economic feasibility of large solar thermal plants in Tunisia. The study examines the conditions concerning climatic, economic and technological aspects for solar thermal and competing technologies. It makes certain assumptions regarding the energy price development and investor expectations to simulate the energy yield and economic viability of solar thermal in the near and mid-term future. Based on case studies for the tertiary and industrial sectors, which were chosen as representative examples for their respective sectors, the study comes to the conclusion that some segments in the tertiary sector, especially those where expensive LPG is replaced (hotels, hospitals and public residences), present good or at least sufficient investment opportunities. Tertiary segments, which rely on cheap natural gas, for the most part do not yet fulfil investor expectations. In the industrial sector, where profitability expectations are higher, average energy price levels are lower and less grant support is available, none of the solar thermal plants simulated in the study comes close to satisfying economic expectations.

The main obstacle for the greater use of solar thermal consists of the fuel subsidies for gas and oil. Another long-term challenge for solar technology providers in Tunisia is presented by investor expectations, in particular the ambitious short payback periods. Based on the results, the study develops recommendations for the promotion of solar thermal in Tunisia in both sectors.

The study was realised within the programmes "Development of the Solar Market in Tunisia (DMS) and the Project "Dissemination of innovative solar thermal applications in the Tunisian industry" (DASTII) funded by the German Federal Ministries for Economic Cooperation and Development (BMZ) and for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB).

2. Introduction



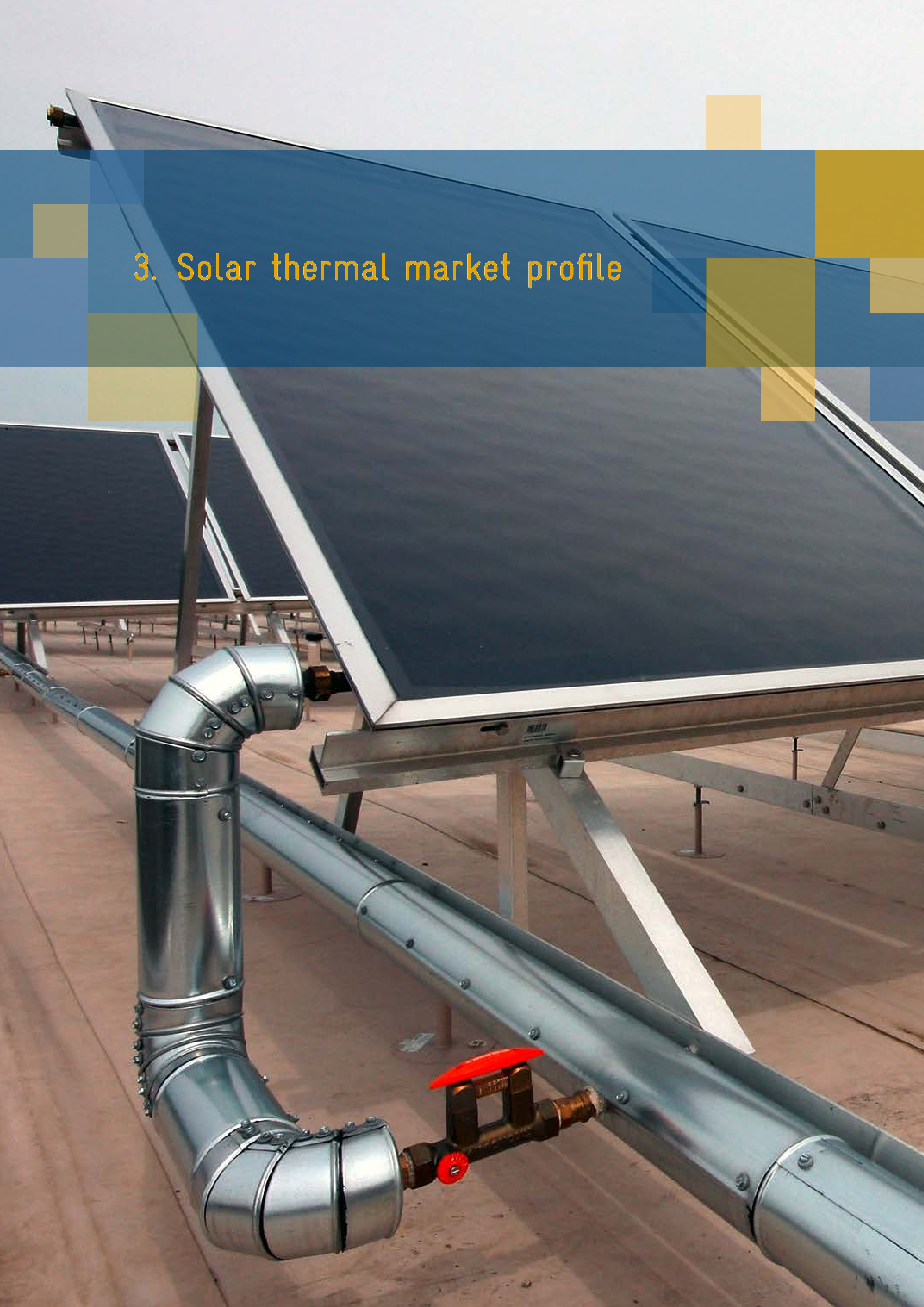
Since 1998, Tunisia has no longer been able to produce enough gas and oil to cover its own growing energy demand. The import of energy, for the most part gas from Algeria, and the subsidising of energy have created of a major burden for Tunisia's national budget. Programmes to alleviate these expenses focus on the reduction of subsidies and promotion of energy efficiency measures and renewable energies.

Solar thermal has proven to be a technology that can reliably produce domestic hot water (DHW) in the residential sector using one of Tunisia's abundant resources – solar irradiation. The successful PROSOL residential programme not only largely contributed to the installation of more than 700,000 m^2 (cumulative) of solar collectors by 2014 but also to the creation of a local industry and employment opportunities, which is essential in a country suffering from high levels of unemployment.[1]

From a technical standpoint, the potential for the use of solar thermal energy extends beyond the residential sector. A multitude of potential applications for low and medium temperature exist all along the tertiary sector for all potential consumers who need large amounts of hot water at low and medium temperature ranges, e.g. hotels, hospitals, swimming pools and public homes and residences, as well as in the industry for process heat. Nevertheless, with existing framework conditions (March 2015) it remains questionable whether these technologies present an economic opportunity for public and private investors and can thus contribute to reaching energy efficiency goals of Tunisia. This study therefore evaluates the economic feasibility of large-scale solar thermal systems by analysing specific system demand and simulating the replacement of conventional fuel sources by solar thermal energy in the tertiary as well as the industrial sector under current framework of subsidies and support.

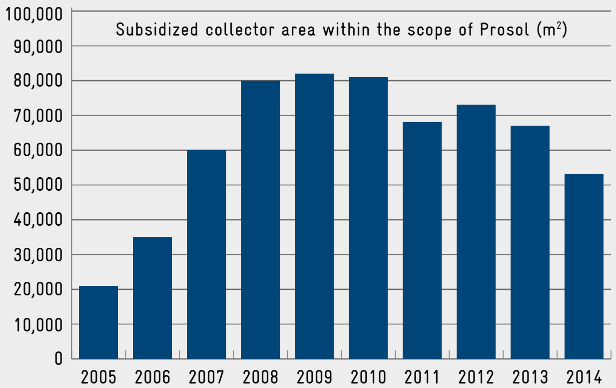
[1] *Since the report will be translated into French leaving many of the tables unchanged, the decision was taken to employ the French and not the English mode of setting decimal points the tables.*

3. Solar thermal market profile



The foundations of the solar thermal market in Tunisia were laid in the 1980s. Initially only slow to develop, the installation of solar thermal water heaters in Tunisia has seen tremendous growth since the introduction of the support programme PROSOL Residential in 2005. Focusing on small-scale solar thermal systems of 2 to 5 m² collector area, the installation capacity increased from 20,000 m² from the year 2005 to an average of 70,000 to 80,000 m² per year since 2008, reaching around 500,000 m² cumulated collector area by the end of 2013.

Figure 1: Installed m² of solar thermal collectors in Tunisia since the initiation of the PROSOL programme



Source: Figures based on ANME[2]

The tertiary and the industrial sector have played only a minor role in market growth, despite the fact that the special support programmes PROSOL Tertiary and PROSOL Industrial were created in 2009 and 2010 to promote growth in both sectors[3].

[2] *http://solarthermalworld.org/content/Tunisia-ups-and-downs-PROSOL-subsidy-scheme, Epp, B. 15 Jan. 2015*

[3] *ib*

The technical potential in the tertiary sector was estimated to be around 600,000 m², with the Tunisian government aiming to install 200,000 m² by 2030.[4] Nevertheless, only 11,500 m² had been installed by 2014.[5] There were similar ambitions in the industrial segment, with 150,000 m² to be installed by 2030; so far, however, less than 1,000 m² has been realized in this sector.[6] At least one major obstacle for the competitiveness of solar thermal technologies appears to be the heavy subsidies for conventional fuels (gas and oil) used for heating purposes, which is still a remnant of an energy policy created in times of abundant fossil resources.

Along with other energy efficiency policy measures, the promotion of solar thermal systems aims at the reduction of energy consumption per capita and thus a reduction of the increasing import costs for oil and gas and energy subsidies. Several institutions are involved in organizing the Tunisian energy sector.

3.1. Institutional framework

The energy sector in Tunisia is regulated by the Ministry of Industry, Energy, and Mines (MIEM). Its department "General Direction of Energy (DGE)" administers the sector.

The relevant institutions in the energy sector are:

- **National Observatory of Energy (ONE)**, which is a statistical unit and responsible for the collection and processing of energy data and the publishing of energy reports.

[4] *TOR to the project "Study of opportunities for solar thermal systems in the tertiary and industrial sectors"*

[5] *http://solarthermalworld.org/content/Tunisia-ups-and-downs-PROSOL-subsidy-scheme, Epp, B. 15 Jan. 2015*

[6] *TOR to the project "Study of opportunities for solar thermal systems in the tertiary and industrial sectors"*

- **The National Agency for Energy Conservation (ANME)** implements energy policies. These include projects and support programmes concerning energy efficiency and the promotion of RE.

- The Tunisian **Company for Electricity and Gas (STEG)** is the main producer of electricity. STEG is also responsible for transmission and distribution of electricity and natural gas (NG).

- The state-owned Tunisian **Company for Oil Activities (ETAP)** administers oil and gas explorations as well as imports for oil and gas. It is obliged to sell imported Algerian NG at € 0.3 to STEG far below import costs.[7]

- The **Tunisian Refining Industry Company (STIR)** refines oil products from national or Algerian sources provided by ETAP at a **fixed price, which is** set by Directorate General for Energy depending on the quality (about 50 TD/barrel).

3.2. Support programmes for renewable energies and solar thermal in particular

Solar thermal technologies and other renewable energies benefit from several laws and decrees which facilitate their installation or financially support investors:

- Full VAT exemptions and reduction of custom duties to 10%.[8]

- Support programmes for RE, which include energy audits, realization and monitoring of demonstration projects, capacity building etc.[9]

- Financial support for RE by levies on other sectors[10] and the creation of the "Energy Transition Fund (FTE)" and foreign support.[11]

- Direct investment incentives.[12]

The solar thermal market in Tunisia developed fast since the creation of the PROSOL programmes in 2005.

3.3. The PROSOL programmes

PROSOL comprises four programmes that focus on the installation and use of solar energy in Tunisia. While PROSOL Elec covers photovoltaics, the remaining three programmes aim at the use of solar thermal energy in the residential, tertiary and industrial sector. All include a mix of grants, favourable loans as well simple payback methods. Flanking measures include support to feasibility studies, quality requirements as well as awareness raising measures.

The programmes aim to mitigate the effect of high oil and gas prices on the international market and to stabilize national fossil fuel resources. It is part of a national energy conservation programme for renewable energy and is supported by international bodies such as United Nations Environmental Programme (UNEP) or the Italian Ministry for the Environment, Land and Sea (IMELS).

3.3.1. Support for small solar thermal installations: PROSOL Residential

PROSOL Residential accelerates the market penetration of solar water heating in Tunisia by targeting domestic financial institutions. Through a temporary interest rate subsidy (phased out 18 months after inception), PROSOL significantly lowered the financing costs of installation by end-users. Loans – contracted through local financial institutions – could be repaid through utility bills. This provided sufficient guarantees for domestic banks to extend five-year loans, instead of the usual three-year term, as well as an interest rate reduction. PROSOL overcame the capital cost barrier through simple and affordable loans (with repayment matching monthly electricity bills) and proved to be an effective incentive for domestic banks (which carry 100% of the loan risk).[13]

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7 *Master thesis Schaffitzel i 2014*

8 ***Decree no. 95-744 (April 24 1995): tax exemptions for RE products** Article 6, section 5*

9 *Law no. 2004-72 (August 2 2004): energy policy and creation of ANME*

10 *Law no. 2005-82 (August 15 2005): financing of energy policy*

11 ***Law no. 2005-106 (December 19 2005): creation of FTE***

12 *Decree no. 2009-362 (February 9 2009): incentive rates*

13 *http://climatefinanceoptions.org/cfo/node/34. 15. Jan. 2015*

PROSOL Residential combines several financial aspects to create a bundle of investment incentives such as grants, VAT exemption, reduced bank loans as well as money collection for loans by STEG:

Table 1: Support framework for PROSOL Residential programme*

System size / specifications	Quality requirement	Incentives			
		Grant	VAT exemption	Interest rate[14]	Loan amount
1-3 m² collector size, 150-200 l storage tank, 900 kWh/a	Solar Key Mark approved collectors	TD 200	√	TMM+1,2%	Max. 1150 TD
3-5 m² collector size, 300-500 l storage tank, 2000 kWh/a	Solar Key Mark approved collectors	TD 400	√	TMM+1,2%	Max. 1150 TD

** Master thesis Schaffitzel 2014*

Results

The programme effectively kick-started the market and certainly contributed to the installation of more than 500,000 m² of SWH by the end of 2013.[15]

In 2012, around 75% were small systems consisting of up 200 l storage tanks (1-3 m² collector area) and around 25% bigger systems with larger storage tanks of 300 l or more (>3 m² collector area).[16] Most systems have been installed in the larger municipalities, especially Sfax and Tunis; meanwhile, in the central areas in particular, the market remains undeveloped. At the end of 2012, Tunisia had about 27 companies active in the production and installation of solar thermal systems.[17]

Non-financial instruments such as awareness building campaigns helped sensitize consumers and private banks, provided education and training for suppliers and commercial banks, as well as certification of solar thermal components (“QUALISOL”).

[14] *Up from initially 0%. From 2005 – 2007. Schaffitzel 2014*

[15] *http://www.unep.org/energy/portals/50177/publications/MIF_brochure_04-01_low_singlepage.pdf. 15. Jan. 2015*

[16] *Gross, Christopher: Le marché solaire thermique en Tunisie, Oct. 2013, http://www.docstoc.com/docs/166733393/Le_march%C3%A9_CES_en_Tunisie. 15. Oct. 2014*

[17] *ib*

The programme PROSOL Tertiary and PROSOL Industrial were initiated in 2009 to promote the use of large solar thermal systems.

3.3.2. PROSOL Tertiary

PROSOL Tertiary focuses on solar water heating projects for the service sector. With an estimated technical potential of 600,000 m², the Tunisian government plans to realize 30,000 m² by 2016, 60,000 m² by 2020 and 300,000 m² by 2030.

Jointly implemented by UNEP, IMELS, and ANME, PROSOL Tertiary’s goal is to support the service sector (e.g., hotels, clinics, sports centres).[18] One of the key incentives is an investment grant of up to 55% of the initial investment.

[18] *http://www.unep.org/energy/portals/50177/publications/MIF_brochure_04-01_low_singlepage.pdf 13 Oct. 2014*

Table 2: PROSOL Tertiary Programme conditions since June 2012*

Issue	Incentive type	Amount	Cap in TD
Investment cost	Grant	Up to 30%, with a maximum of TD 150/m² for the collector by Energy Transition Fund (FTE).	TD 150/m²
Investment cost	Grant	Additional Investment grant of up to 25% with a maximum of TD 150 /m² of solar collector area paid by the Fund MIEM/UNEP	TD 150/m²
Demonstration projects	Grant	A grant of up to 70% for feasibility studies of up to	TD 70,000
O&M	Grant	Operation & Maintenance (O&M) subsidy of TD 6/m² collector area per year for four years after warranty expiration paid by MIEM/UNEP	TD 6/m²
Interest rate	Reduction in interest rate	Reduction of 2% in interest rate on market rates	
Quality	Restriction	Solar Key Mark approved collectors only	
VAT	Exemption	Full VAT exemption	
Import tax	Reduction	Reduction of import tax to 10%	

** Master thesis Schaffitzel i 2014*

Results

By the end of 2014, PROSOL Tertiary had supported the installation of around 11.500 m².[19]

3.3.3. PROSOL Industry

In Tunisia, industries use around 70% of the overall energy supply for process heat. Important industries include the construction material industry, and the food, chemical, mechanical, electrical and textile industries. Many industries use either hot water or steam at temperatures lower than 250°C for heat supply, which can be provided with solar thermal technologies. PROSOL Industry was launched to support solar thermal energy in replacing either gas or oil for heating purposes, and aimed at installing 15,000 m² of collector area by 2016 and ultimately 150,000 m² by 2030.[20] The estimated technical potential nationwide is about 363,000 m², which corresponds to a market value of about US$ 210 million.[21]

So far, support has focused on feasibility studies as well as on grants for demonstration and commercial projects.

[19] *http://solarthermalworld.org/content/Tunisia-ups-and-downs-PROSOL-subsidy-scheme, Epp, B. 15 Jan, 2015*

[20] *Schaffitzel 2014*

[21] *http://solarthermalworld.org/content/mediterranean-investment-facility-building-success-stories-and-partnerships-2014 13 Oct. 2014*

Table 3: PROSOL Industrial – overview of programme

Issue	Incentive	Incentive	Cap in TD
Energy audits	Grant	70% of costs	30000
Demonstration projects	Grant	50% of total costs	100000
Investment energy conservation	Grant	70% of immaterial costs (e.g. feasibility studies, design, etc.)	70000
Substitution of natural gas in industries	Grant	20% of costs for installations	400000
Solar water heating for commercial and industrial projects	Grant	30% of investment costs	150 TD/m²

Investment incentives for RE in the Tunisian Industry; source: Decree. 2009-362, Art. 1[22]

Results

Up to now, no projects or feasibility studies have been realised under the PROSOL Industry regime.

3.4. Other relevant activities in the solar thermal sector

Only one large demonstration plant that has been installed at the site of a textile manufacturer with 955 m² of flat plate collector area was outside of PROSOL with major financial support of IMELS. In addition, a series of feasibility studies were carried out for several companies in different industrial sectors until today to evaluate energy consumption, energy efficiency improvements as well as the appropriateness of the use of renewable energy. These were financed through Italian and German cooperation.

3.5. Heat generation with conventional technologies and subsidies

Heat, which can be generated with solar thermal technologies, is conventionally provided with natural gas (NG), liquefied petroleum gas (LPG), light and heavy oil or electricity, depending on the sector, site and accessibility of heating sources.[23]

- **Natural Gas (NG)** from national or Algerian sources is the dominant factor for heat and electricity production. Domestic natural gas production is not sufficient, and covers only 53% of primary energy consumption, while the import of Algerian gas supplies 47%. Electricity generation represents 73% of the total consumption of natural gas, the rest (27%) is consumed by the industry and housing. Gas is provided either as natural gas via pipelines or as liquefied natural gas (LNG) for those users who do not have direct access to a pipeline.

- **Liquefied petroleum gas (LPG)** is a by-product of oil or gas production as well of the oil refining process. It is provided to consumers in gas tanks or bottles and is therefore usually not suitable for large-scale industrial consumers. It is commonly used in the tertiary sector.

- **Fuel oil** can be used at tertiary and industrial sites that do not have direct gas access. It usually has to be transported via pipelines or trucks to the point of consumption and is considerably more expensive than natural gas - approximately by 16%/MWh. The use of light oil might be applicable for tertiary sector purposes, but no case for its use has been covered in the study.

- **Electricity** can be used to support the heating processes, but since primary energy losses are high, it is usually the most expensive option. It normally supports heat supply by providing energy for pumping processes.

[22] *In: Schaffitzel 2014*

[23] *In: Schaffitzel 2014*

Fuel subsidies

Most conventional fuels are highly subsidized. Industry and tertiary consumers are benefiting from up to 47% lower gas or oil prices compared to purchase prices of the utilities in 2014. Tunisia provides energy below market rates to energy consumers. Being a net importer of energy, Tunisia therefore does not evenly distribute the energy below market rate, but also provides financial support for energy consumption from the state budget. The lack of financial incentives lowers the need for companies to reduce energy consumption or to replace conventional energy carriers with renewable energies.

Table 4: Subsidies for fuel oil and gas 2014

Fuel type	Gas	Heavy fuel	Unit
Price before Subsidy	70	85	TD/MWh
Price after Subsidy	38	45	TD/MWh

Source GIZ Tunisia

4. Solar thermal technologies and applications

The following section gives a brief overview of relevant technologies and evaluates the suitability of the technology for Tunisia.

4.1. Overview

The most important solar thermal systems component is the solar collector.

Solar thermal collectors convert solar radiation into usable heat. A number of technologies - including unglazed, flat plate, evacuated tube and concentrating collectors - are available on the market to provide the appropriate temperatures and efficiencies needed by the different applications.

Exposed to the sun, the collector heats up a heat transfer liquid (either water, water with glycol for frost protection or thermo oil). The collectors are connected to the system or to a storage tank, either directly or via a heat exchanger. Electric pumps circulate the heat transfer liquid within the solar circle.

In addition, we differentiate between static technologies, where the collectors are orientated towards the sun on fixed racks, and tracking technologies that follow the sun on one axis. Systems which follow the sun on two axes are only common in India (dish collectors) or are used for generating electricity. These technologies are not part of this report. Also, unglazed collectors and small thermosiphon systems are not part of this study.

4.2. Collector types

4.2.1. Flat plate collectors (FPC)

FPC have a market share of 90% in Europe, because they are for the most part sufficient for domestic hot water (DHW) applications. If a higher temperature than 60°C is needed, the FPC can be equipped with thicker insulation and a second transparent layer at the front, which can be glass or a foil.

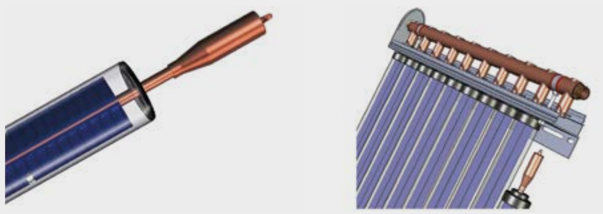
Source: Bosch Thermotechnik

4.2.2. Evacuated tube collectors

There are different types of evacuated tube collectors (ETC) available. With direct flow types, the heat transfer liquid flows through the tube. With so-called heat pipe collectors, a separate circuit inside the tube transports the collected heat to the top of the tube. Inside the header pipe, the energy is transferred to the heating circuit.

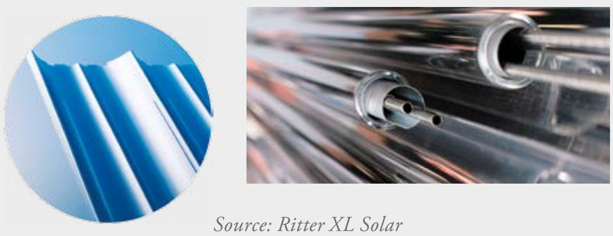
To improve efficiency, some types of ETC are equipped with a reflective metal sheet behind the tubes (a so-called “mirror”, which can be flat or shaped), which are called compound parabolic concentrators (CPC).

Figure 2: Heat pipe evacuated tube collector



Source: Narva

Figure 3: Direct flow ETC with mirror (CPC)



Source: Ritter XL Solar

4.2.3. Evacuated flat plate collectors

This technology is quite new and is not yet very common. It combines the positive characteristics of FPC and ETC. The modules are quite small, in order to withstand atmospheric pressure. The collectors are still quite expensive; therefore they are not included in the case studies.

4.2.4. Concentrating solar technologies

Concentrating solar technologies work on the principle of reflecting and concentrating direct solar radiation at its focus (a point or line), thereby using the concentrated solar radiation as a high-temperature thermal energy source to produce electricity or process heat. The mirror elements used to reflect and concentrate solar radiation vary in geometry and size. To facilitate concentration of direct normal irradiation (DNI), the mirrors need to be continuously tracked following the path of the sun on one or two axes.

Parabolic trough collectors and Fresnel collectors with plane, linear mirrors have been successfully demonstrated. The sunlight is reflected and directed to the receiver tubes. The mirrors or troughs are mostly aligned on a north-south axis and rotate from east to west to track the sun along its daily path.

The concentrating systems can generate heat with temperatures of up to 400°C and can be operated by pressurized water or thermal oil. Alternatively, the system can generate steam directly in the collector. Boiler feed water runs through the receiver tubes to absorb the concentrated sunlight, which leads to steam generation. The steam can be either used in a turbine to produce electricity or directly used for industrial processes. Residual heat can be used for supplemental heat applications.

Linear Fresnel collector

Source: Industrial Solar

Parabolic trough collector

Source: Solarlite CSP

4.3. Temperature ranges

Which solar thermal collector type is used depends greatly on the required temperature level. In some applications, e.g. for washing processes, only a low temperature of about 50°C is needed. For this temperature, mainly flat plate collectors are used. Numerous industrial processes necessitate temperatures of up to 95°C. Both evacuated tube collectors and improved flat plate collectors are able to provide this temperature level with a high degree of efficiency.

Higher temperature levels can be reached if vacuum technology is used for insulation; either evacuated flat plate or evacuated tube collectors are collector types which are used with industrial applications.

Above approximately 140°C, solar radiation must be concentrated. The higher concentration factors of parabolic trough or linear Fresnel collectors provides operating temperatures up to 400°C. These concentrating technologies only make use of direct sunlight and must constantly track the sun.

The following table summarizes the three distinct temperature ranges in which solar thermal collectors and their corresponding applications and technologies operate.[24]

Table 5: Collector temperature ranges, applications and technologies; source: Renewable Heating and Cooling Technology Platform (RHC TP)

Temperature needed by the application	Type of application	Collector technologies used
Low temperature 20° C - 95° C	Swimming pools, domestic hot water heating, space heating, district heating, solar cooling and low temperature process heat	Unglazed, flat plate, evacuated tube and CPC concentrator collectors
Medium temperature 95° C - 250° C	Process heat, desalination, water treatment, high efficiency solar cooling, district heating and cooling	High efficient vacuum insulated flat plate, evacuated tube, CPC and other low concentrating, linear Fresnel and parabolic trough collectors
High temperature > 250° C	High temperature process heat and electric power via thermal cycles	Parabolic troughs and linear Fresnel collectors, solar dishes and solar towers

Most applications can use more than one collector type. The criteria to be considered are available space, economics, location and others. This is the reason why the case studies later in this report compare two appropriate collector types.

4.4. Different types of solar systems

4.4.1. Thermosiphon systems

In Southern Europe and North Africa, high solar radiation and temperate climate make the use of simple and cheap thermosiphon systems possible. With this technology, the solar heat transfer fluid circulation is naturally driven, since the water storage is installed above the solar collector. Usually 2 to 3 m² flat plate collector area and 150 to 300 litres of storage are used for a family of four. The solar fraction for DHW achieved is about 50% to 60%. An auxiliary electric water heater providing support for days without sufficient sunshine is either integrated into the storage tank or can be adapted within the building.[25]

Nearly all systems in Tunisia that benefit from the PROSOL residential support programme are thermosiphon systems. Low costs, the limited complexity of the technology and installation, as well as the reliability of this technology make it easy to install and connect to the residential hot water system.[26]

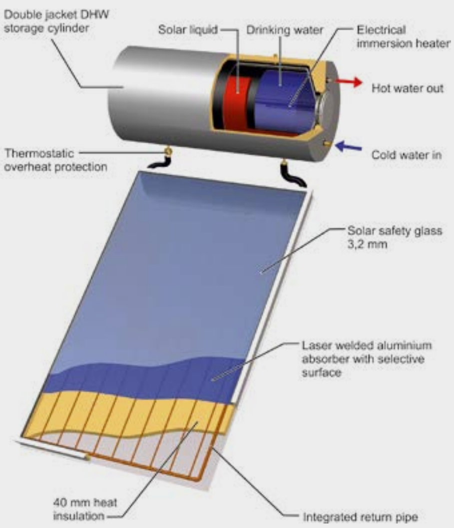
[24] *Good overviews of the different technologies can found at: http://www.rhc-platform.org/structure/solar-thermal-technology-panel/, 27. Jan. 2015 http://en.wikipedia.org/wiki/Solar_thermal_collector, 27. Jan. 2015*

[25] *http://www.rhc-platform.org/fileadmin/Publications/Solar_Thermal_SRP_single_page.pdf, 26 Oct. 2014*

[26] *For a technical and economic description of the market compare : Gross, Christopher: Le marché solaire thermique en Tunisie, Oct. 2013, http://www.docstoc.com/docs/166733393/Le_march%C3%A9_CES_en_Tunisie, 14. Jan. 2015*

Thermosiphon systems usually consist of flat plate or vacuum tube collectors and an insulated storage tank with or without additional electrical immersion heater.[27]

Figure 4: Schematic depiction of a thermosiphon system



Source: Wagner Solar

4.4.2. Small solar systems with forced circulation

In regions exposed to frost, only forced circulation solar thermal systems are used. The collector is installed on the roof and the hot water storage is usually situated in the basement. The solar heated transfer fluid circulates through the hydraulic solar circuit with the help of a pump. Typically, a 4 to 6 m^2 flat plate collector area and a 300-litre store are used for a family of four. The solar fraction for DHW achieved is about 60%. A special version of the forced circulation type is the so called "drain-back" system, where the heat transfer fluid is pumped through the collector only when the solar system is active, whereas it is stored in a tank while the system is inactive.[28]

For Tunisia, forced circulation systems might be useful for buildings with an above-average energy efficiency standard or for larger and more complex systems as well as for mountain lodges exposed to frost. For most small-scale applications, thermosiphon system will be the more cost efficient solution for DHW.

The higher price and complexity of the system and its installation make it the less attractive option compared to thermosiphon systems for climate zones in which both types could be used. It was assumed that the market share and market potential of higher-priced pumped systems for DHW is very small in Tunisia and has therefore not been considered in the study, since these are mostly residential applications.

Forced circulation DHW system: In addition to the flat plate or vacuum tube collectors, a storage tank is connected via a pump and heat and flow control sensors.[29]

Figure 5: Schematic depiction of a forced circulations DHW system

Source: Wagner Solar

4.4.3. Combisystems for one and two family homes

These systems are mainly used in Central Europe, especially in Germany, Austria and Switzerland. In addition to DHW, these systems provide space heating. In Central Europe about 50% of newly installed systems are combisystems, usually with a 10 to 15 m^2 flat plate collector and a 600 to 1000-litre hot water storage tank.

[27] *For further technical information: Analyse de la chaîne de valeur des technologies relatives à l'énergie solaire en Tunisie, 2013, page 90.*

[28] *ib*

[29] *For further technical information: Analyse de la chaîne de valeur des technologies relatives à l'énergie solaire en Tunisie, 2013, page 92.*

In a well-insulated building, the solar fraction is about 25% of the overall building heat demand for DHW and space heating. The systems work best with low temperature heating systems such as floor heating.

In Tunisia, the use of combisystems might be applicable for new buildings with a high-energy efficiency standard and a heating system. In general, the average building standard in Tunisia does not have sufficient insulation or in many cases a heating system. Due to these preconditions, it was assumed that the market share and market potential of higher-priced pumped systems for DHW and space heating is very limited in Tunisia; for this reasons, these cases were not considered in the study.

Combisystems for DHW and space heating
Combisystems usually have considerably more collector surface (7 to 20 m²) and a larger storage tank (700 to 1000 l). The buffer tank that often contains a reservoir for DHW is connected to the heating system of a house.[30]

Figure 6: Schematic depiction of a combisystem

(Source: Wagner Solar)

4.4.4. Collective solar thermal systems

In multi-family homes as well as (semi-)public buildings with high DHW demand (hospitals, hotels, boarding schools, retirement homes, military or police stations, sports facilities), solar thermal energy can be provided through larger solar thermal systems. These systems are forced circulation systems with the collector area on the roof and central hot water storage tank in the basement. A typical size is 0.5 to 1 m² of collector area per occupant and 50-litre hot water volume per m² of collector area.

In Tunisia, the programme PROSOL Tertiary has focused on this market segment with considerable success. The technology seems to be appropriate for all kinds of large buildings with a larger number of households or consumers. Nevertheless, a central water heating system with a large storage tank is required in order to provide all connected parties with DHW produced with solar energy. Buildings with centralised production of large quantities of hot water are therefore considered in this report (see case studies for hotels, hospitals and residencies in this report).

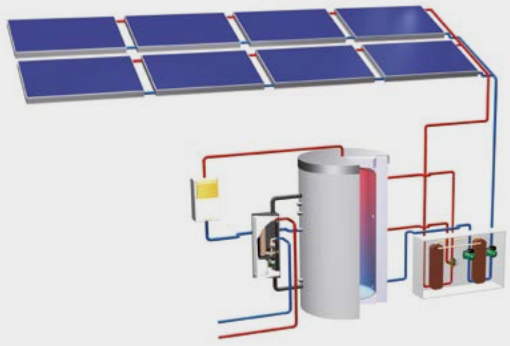
Multi-family houses that have decentralized water heaters based on gas or electricity are not suitable to be equipped with solar. In addition, diversified ownership complicates the installation process of a collective solar system.[31] Though it might be a technically viable solution for new multifamily houses, especially those belonging to just one housing company, the market potential is considered to be very limited for this segment. Therefore no case study was carried out. The focus was on collective system in single or public ownership (hotels, hospitals, residencies).

Large solar thermal systems
Technically, the large solar thermal system does not necessarily vary much from the DHW or the combisystem, although the collector area, size of each single collector and storage system differ in size and volume. However, the design and the installation and the connection to the heating system require much more in-depth knowledge due to the increased complexity.

[30] *For further technical information, see: International Energy Agency (IEA) Solar Heating & Cooling Programme Task 26 on Solar Combisystems*

[31] *See also the study "Etude du developpement des systems solaires thermiques collectifs dans le residentiel", GIZ/ANME/CAMI 2011).*

Figure 7: Schematic depiction of a large solar thermal system



(Source: Wagner Solar)

4.4.5. Solar district heating systems

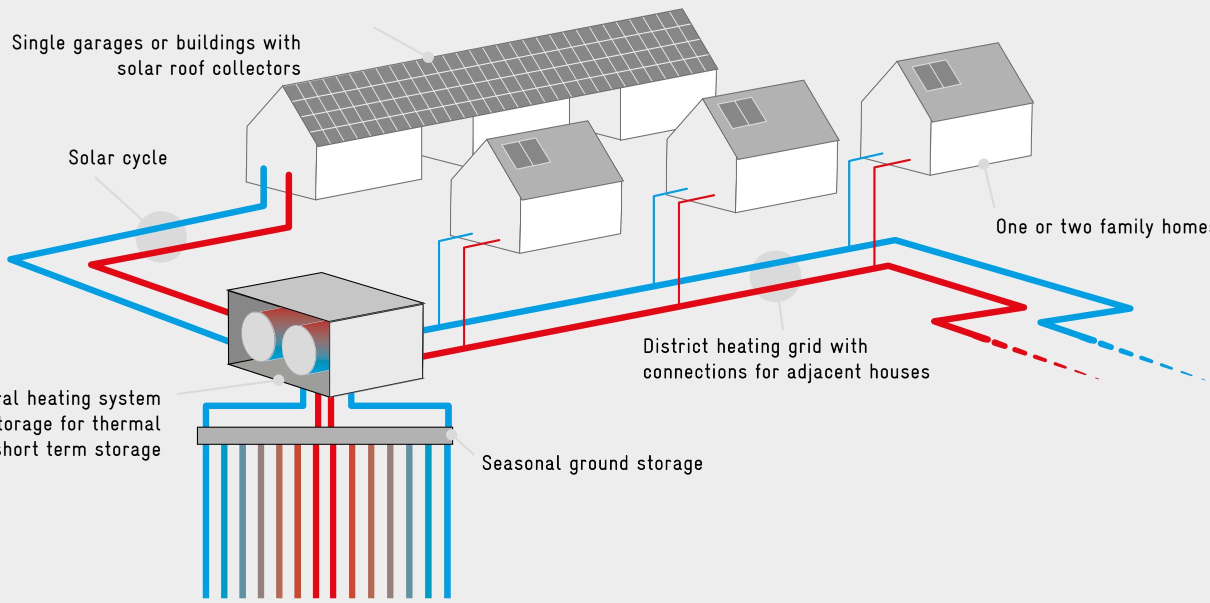
Buildings that do not have sufficient rooftop area to produce enough solar energy on their own can be supplied with solar thermal energy via a district heating (DH) network. DH systems can supply high-density urban areas with different renewable energies and combined heat and power (CHP) plants. Large solar thermal systems supporting DH range from several hundred m² up to 100,000 m². This technology is popular in Central and Northern Europe where district heating systems have been common and require little or no new infrastructure. In countries like Denmark, the share of DH even exceeds 50%.

In Denmark, Germany and Sweden, special solar district heating pilot systems integrate large, seasonal heat storage with a water volume of tens of thousands of cubic metres to increase significantly the solar fraction of the DHW system. Since the surface of these storage systems is small compared to their volume, their heat losses are mostly quite low. As a result, a total share above 50% of the space heating demand can be provided by solar energy harvested in summer.[32]

In Tunisia district heating systems are not common, and most existing dwellings do not have sufficient infrastructure, e.g. central heating systems, to enable a connection to such a heating system. With the possible construction of new city districts, district heating might become a technically viable, but expensive option. District heating systems have therefore not been considered for this study.

District heating networks with solar support are often connected to large solar thermal collectors, often considerably larger than conventional rooftop collectors. They can either be mounted on the ground or on the roofs of buildings. All collectors feed into the same grid to distribute or store the energy in large storage areas.

Figure 8: Schematic depiction of a district heating network



Source: AEE-Intec

[32] *http://www.rhc-platform.org/fileadmin/Publications/Solar_Thermal_SRP_single_page.pdf, 26. Oct.2014*

Large collector field for DH in Denmark

Source: Acron-Sunmark

Excursus

District heating networks for industrial processes have so far not yet been used on a large-scale industrial level since required temperatures are often high and storage or transport losses can also be high. Additionally, these fields would require large conglomerates of industries needing similar temperature levels and extensive space for setting up collector fields on empty sites or roofs. As these preconditions rarely occur, they have not been considered for the study.

4.4.6. Solar thermal assisted cooling

Since the demand for cooling is increasing worldwide, the extra electricity required for cooling machines during the summer is presenting a growing burden on electricity systems. Solar thermal assisted cooling is an interesting option, which can help to reduce electricity peak loads during summer and during the night as well.

A few hundred solar thermal assisted cooling systems have been installed in Europe and the rest of the world. However, the investment cost of a solar thermal cooling system is roughly double that of a solar heating system. The solar thermal cooling installation requires a sorption-process driven machine as well as the collector field, plus a storage tank. To compete in the cooling market, the cost of electricity has to increase considerably. Also, in this market segment, solar thermal finds itself in direct competition with other renewable energy technologies such as photovoltaics, which are able to provide cheap electricity while offering simple integration methods that are independent of the cooling system. Photovoltaic systems in particular have seen a huge drop in investment costs in recent years.

Since for Tunisia, solar heating is much closer to competiveness, thermally driven cooling machines have not been considered in the study. Also, it must to be noted that the upcoming and quickly growing PV market might resist strong competition in this market segment.[33]

World's largest solar cooling installation at Desert Mountain High School, Arizona

Source: Solid

[33] *See also "Enabling PV" - https://energypedia.info/images/1/10/ENABLING_PV_Tunisie_fr_web.pdf*

4.4.7. Solar thermal process heat systems

Based on the wide range of temperatures, the suitable collector technologies for industrial process heat are flat plate collectors, vacuum tube collectors or even parabolic trough or Fresnel collectors.

In Tunisia, approximately 28% of the final energy demand in 2010 was used for process heat in industry and agriculture.[34] Solar thermal energy could cover a part of this demand.

Tunisia benefits from high solar irradiation levels and has a wide variety of different industries such as agro-industrial, food, textile and construction etc., that often utilize temperatures below 400°C or even below 250°C. The use of solar thermal is a suitable technology for providing large quantities of heat.

400 m² solar process heat installation at paint shop, Gränichen/CH

Source: Ritter XL Solar

The possible applications for solar process heat have been analyzed around the world.

[34] *Schaffitzel 2014, with World Bank figures*

Table 6: Suitable applications for solar process heat[35]

Sector	Process	Temperature (°C)
Various sectors	Make-up water	20–110
	Preheating	20–100
	Washing	30–90
Chemicals	Biochemical react.	25–55
	Distillation	100–200
	Compression	115–170
	Cooking	85–105
	Thickening	125–140
Food & beverages	Blanching	60–95
	Scalding	45–85
	Evaporating	40–130
	Cooking	70–120
	Pasteurization	60–145
	Smoking	20–85
	Cleaning	60–90
	Sterilisation	100–140
	Tempering	40–80
	Drying	40–200
	Washing	35–80
Paper	Bleaching	40–150
	De-Inking	45–70
	Cooking	110–180
	Drying	95–200
Fabricated metal	Pickling	20–100
	Chromating	20–75
	Degreasing	20–100
	Electroplating	30–95
	Phosphating	35–95
	Purging	40–70
	Drying	60–200
Rubber & plastic	Drying	50–150
	Preheating	50–70
Machinery & equipment	Surface treatment	20–120
	Cleaning	40–90
Textiles	Bleaching	40–100
	Coloring	40–130
	Drying	60–100
	Washing	50–100
Wood	Steaming	75–90
	Pickling	40–70
	Compression	120–170
	Cooking	80–90
	Drying	40–150

Excursus: Supply level integration or process level integration

Industrial heating systems are complex and widespread. The question often arises regarding where to best integrate the solar thermal system. On the process level, solar thermal directly supports one specific industrial process; on the supply level, heat is used for supporting a hot water or steam boiler. The heat is then distributed by the existing network. Without knowing the specific company and site, it is not at all possible to provide a recommendation as to which approach is more suitable and economical.[36]

Excursus: Direct steam generation

Concentrating systems can generate steam directly in the collector loop. Thus, a heat exchanger is not needed. If steam is needed in industrial processes, therefore, the direct steam generation (DSG) concept is the easiest method. The solar field is operated in parallel with the existing process heat boiler(s). Saturated steam is separated from

[35] *http://www.uni-kassel.de/upress/online/OpenAccess/978-3-86219-742-2.OpenAccess.pdf, 28 Jan. 2015*

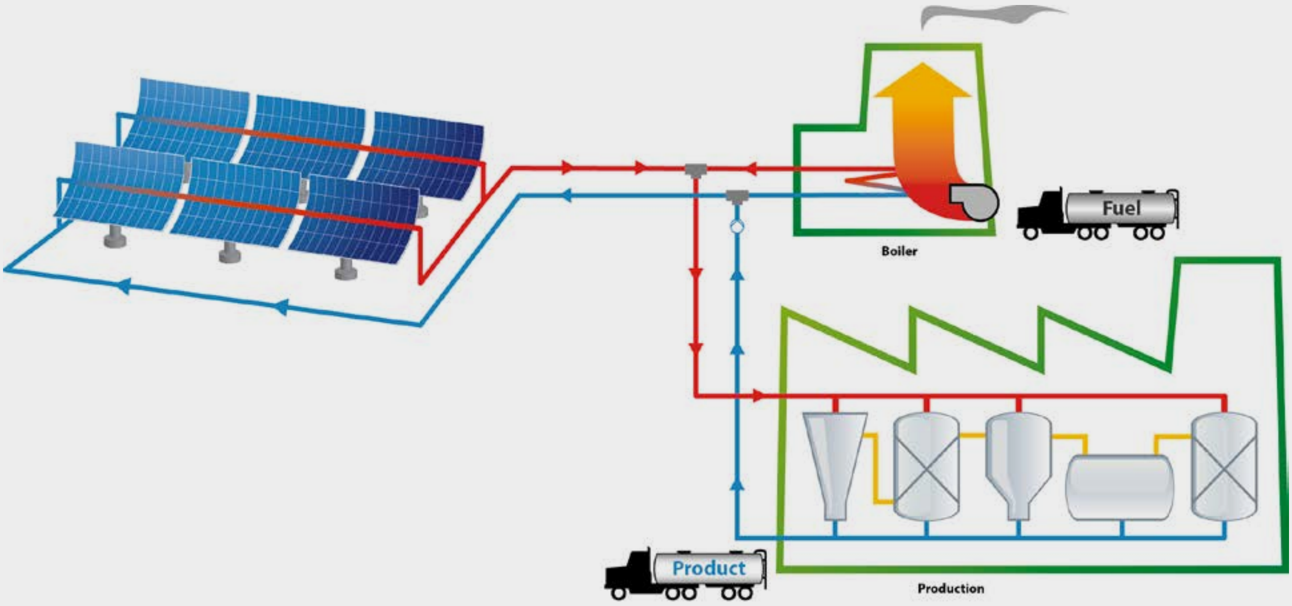
[36] *For an extensive summary and description, see Schaffitzel, 2014, https://energypedia.info/images/e/e7/Solar_Heat_for_Industrial_Process_in_Tunisia._An_Economic_Assessment_with_Policy_Recommendations.pdf , 16 Oct. 2015*

the two-phase media and conditioned according to the required steam parameters. The solar steam header line is connected to the existing main header. During sunshine hours the conventional boilers reduce their output and operate at partial load. This ensures that the production facilities are always supplied at their required demand. The consumers supplied at the steam distribution network are not affected by fluctuating radiation, since the conventional boilers modulate their load accordingly.

If the industrial process fluctuates significantly and needs low pressure steam of up to 3 bar, it still might be more adequate to generate pressurised hot water, which can be stored more easily. If the process does not need the solar energy for several minutes, the hot water can be stored, whereas the direct steam generating solar system would have to go into standby.

Until now, however, direct steam generation systems for process heat are only offered by very few technology providers; at the same time, they still have to prove their performance in commercial applications.

Figure 9: Schematic depiction of a solar direct steam generation network



(Source AEE-Intec)

4.5. Technology evaluation for Tunisia

The following table gives a summary of applications and solar thermal systems that have been described in this report. The main characteristics such as temperature, system costs and relevance for Tunisia determine the selected cases, which will be examined in detail in the next chapters.

Table 7: Solar thermal technology evaluation for the study

Application	Technology applied	Use case / sector	Temperature range	System cost	Main subsidy in Tunisia	Local manufacturing (FPC = Flat plate collector (small))	Complexity of installation	Appropriateness for Tunisia	Cases selected for study
Pool heating	Unglazed absorbers / collectors	Private / public swimming pools	20 – 40°C	Very low	No subsidy	No	Very simple	Yes	
DHW	Flat plate, vacuum tube collectors thermosiphon	Residential	20 – 95°C	Low	TD 200 to TD 400 / system	FPC Small only	Simple	Yes	
(D)HW	Flat plate, vacuum tube collectors forced circulation	Residential	20 – 95°C	Medium	TD 200 to TD 400/ system	FPC Small only	Medium	If thermosiphon not possible	
		Tertiary		High	Up to 300 TD^2		High	Yes	X
		Industrial		High	Up to 150 TD/m^2		High	Yes	X
(D)HW, Space heating	Flat plate, vacuum tube collectors forced circulation	Residential	20– 95°C	Medium	TD 200 to TD 400/ system	FPC Small only	High	Rarely, central heating systems not common	
		Tertiary		High	Up to 300 TD/m^2		Very high	For large systems only, e.g. hotels, hospitals	X
		Industrial		High	Up to 150 TD/m^2		Very high	Rarely, for large systems only	

District heating	Flat plate, vacuum tube collectors	Residential, tertiary, industry, sector	20 – 95°C	Medium – high	Up to 300 TD/m²	No	High	No district heating systems exist in Tunisia	
Solar cooling	Flat plate / vacuum tube collectors	Residential,	60 – 105°C	Very high		No	Very high	Only for pilot / demonstration systems	
	Flat plate / vacuum tube collectors, concentrating collectors	Tertiary	60 – 250°C	Very high			Very high	Only for pilot / demonstration systems	
		Industry	60 – 250°C	Very high			Very high	Only for pilot / demonstration systems	
Industrial processes	Flat plate / vacuum tube collectors, concentrating collectors	Industry	40 – 250°C	Very high	Up to 150 TD/m²	No	Very high	Yes	X

5. Methodology of the case study analysis

5.1. Simulation with T*SOL

In this study, the Valentin Software programme T*SOL Pro 5.5 is used for energy yield simulation. T*SOL allows the user to accurately calculate the yield of a solar thermal system dynamically over the annual cycle. With T*SOL the user can optimally design solar thermal systems, dimension collector arrays and storage tanks, as well as calculate economic efficiency.[37] The heat demands are specific to each case study and are discussed in the corresponding section.

The different solar plant cicuits have been simulated using five different hydraulic schemes. For each case study, two different and appropriate collector technologies have been considered. The hydraulic schemes and the collector technologies are discussed in the following section.

The parameters of the simulated systems can be seen in the attached T*SOL reports. Each report describes each identified optimal system in detail, according to energy yield and economics.

5.1.1. Hydraulic schemes

The choice of each hydraulic scheme depends on the heat demands to be supported by solar thermal systems. The demands supported by solar system are:

- domestic hot water
- domestic hot water and space heating
- indoor pool heating
- hot water for industrial processes
- steam for industrial processes

[37] *For more information on the software see http://www.valentin-software.com.*

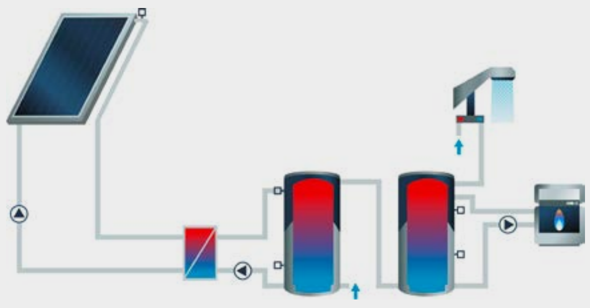
5.1.1.1. Domestic hot water

Typical for Tunisia is the use of one or more solar preheated tanks (left tank in the scheme) followed by a conventionally heated standby tank (right tank in the depiction).

As shown in the schematic depiction, the system consists of:

- solar loop
- preheating tank
- standby tank
- boiler
- DHW consumer

Figure 10: Hydraulic scheme for solar supported DHW



(Source: Valentin Software)

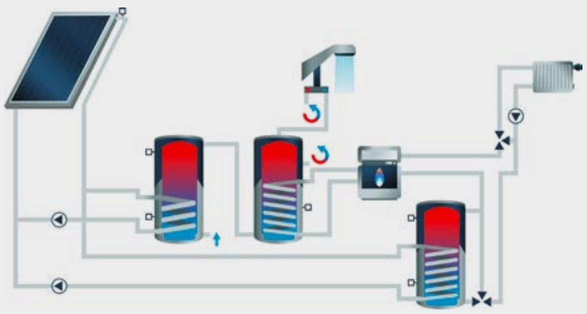
For large collector arrays, the preheating tank is separated into several equal sized tanks. The heat exchangers for the collector loop and the boiler are incorporated as external heat exchangers.

The distribution of hot water follows a closed circulation loop. The standby tank is always heated to 60°C to avoid Legionnaires' Disease.

5.1.1.2. Domestic hot water and space heating

This system corresponds to the system for hot water. In addition to the existing system, an extra buffer tank is loaded by the solar plant. This tank is used to raise the outlet temperature of the heating circuit.

Figure 11: Hydraulic scheme for solar supported DHW and SH

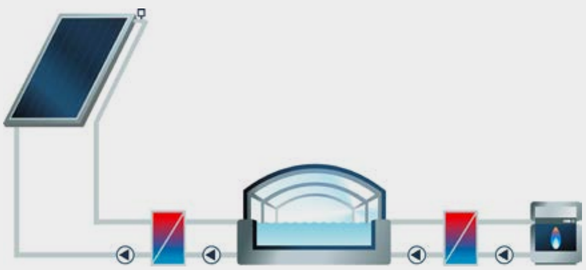


(Source: Valentin Software)

5.1.1.3. Indoor pool heating

In this system concept, the solar plant supports the heating of the indoor pool. The water is heated once a year, after which point the temperature is kept stable at a fixed level. Fresh water has to be added to the pool on a daily basis. Nevertheless, most energy is used to compensate evaporation losses. In addition to the solar plant, a boiler provides the remaining heat demand.

Figure 12: Hydraulic scheme for indoor pool heating

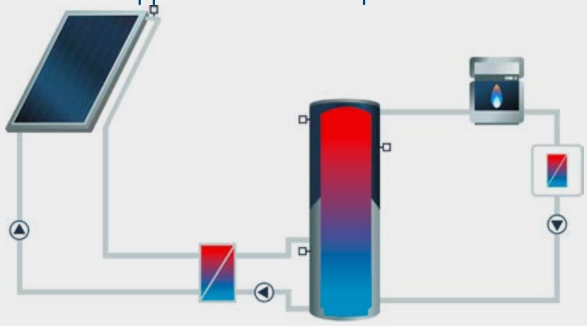


(Source: Valentin Software)

5.1.1.4. Hot water for industrial processes

The system consists of a collector loop, a solar preheating buffer tank, a boiler and the process heat consumer. The process is defined by the inlet and outlet temperatures and the energy demand. In case of low tank temperatures a valve allows a bypassing of the tank. The remaining heat demand is generated by the boiler.

Figure 13: Hydraulic scheme for solar supported industrial processes



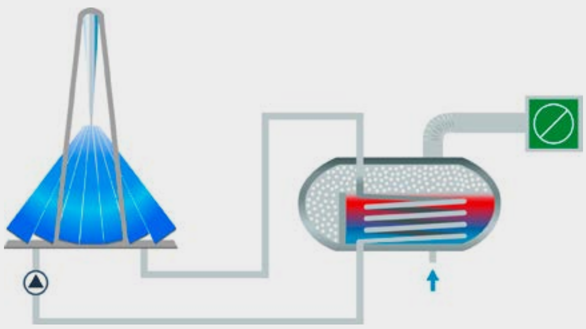
(Source: Valentin Software)

The heat exchanger for the collector loop is integrated into the circuit as external heat exchanger.

5.1.1.5. Steam for industrial processes

This system consists of a collector loop and a kettle-type steam generator. The process is defined by the feed water temperature, the saturation steam pressure and the mass demand. The solar generated steam is fed into the steam network.

Figure 14: Schematic depiction of steam generation processes



(Source: Valentin Software)

5.1.2. Collector technology

For each case study, two collector technologies from the following list are investigated, depending upon the demanded temperature levels:

- flat plate collectors
- vacuum tube collectors (CPC)
- concentrating collectors (Fresnel)

The parameters are listed in the following sections.

5.1.2.1. Flat plate collector

The following table describes the technical data of a typical flat plate collector that can be found on the Tunisian market. In Tunisia, solar thermal collectors have to correspond with exigencies according to the Solar Key Mark label.[38]

Table 8: Technical data for flat plate collectors*

Type:	flat plate collector
Size:	
Gross surface area:	1 m^2
Active surface area:	1 m^2 (Aperture area)
Heat capacity:	
Specific heat capacity:	4560 Ws/(m^2 K)
Heat losses:	
Simple heat transfer coefficient:	4,269 W/(m^2K)
Quadratic heat transfer coefficient:	0,0143 W/(m^2K^2)
Optical losses:	
Conversion factor:	73,3%
Incident angle modifier (IAM) for diffuse radiation:	89%
Incident angle modifier for direct irradiation with an incident angle of 50°:	94%

**Own research*

5.1.2.2. Vacuum tube collector – compound parabolic concentrator (CPC)

Vacuum tube collectors are rare on the Tunisian market and are not produced locally. Prior to the implementation of quality standards (QUALISOL), there had been some bad experience due to inferior quality of imported products, resulting in a bad image for this collector technology type in Tunisia. However, these collectors have proven to achieve significant energy savings performance in other areas of the world. As a rule of thumb, CPCs are more energy-efficient than FPC, but also come with higher costs. This study considers the following data for CPC simulations.

Table 9: Technical data for vacuum tube collectors*

Type:	vacuum tube collector
Size:	
Gross surface area:	1 m^2
Active surface area:	1 m^2 (Gross surface area)
Heat capacity:	
Specific heat capacity:	9180 Ws/(m^2 K)
Heat losses:	
Simple heat transfer co-efficient:	0,749 W/(m^2K)
Quadratic heat transfer coefficient:	0,005 W/(m^2K^2)
Optical losses:	
Conversion factor:	64,4%
Incident angle modifier (IAM) for diffuse radiation:	86,33%
IAM along pipe:	IAM across pipe:
0°: 100%	0°: 100%
5°: 100%	5°: 100%
10°: 100%	10°: 101%
15°: 100%	15°: 101%
20°: 100%	20°: 101%
25°: 100%	25°: 101%
30°: 99%	30°: 102%
35°: 98%	35°: 102%
40°: 98%	40°: 102%
45°: 96%	45°: 102%
50°: 95%	50°: 103%
55°: 91%	55°: 106%
60°: 89%	60°: 111%
65°: 80%	65°: 113%
70°: 76%	70°: 104%
75°: 55%	75°: 86%
80°: 25%	80°: 61%
85°: 7%	85°: 32%
90°: 0%	90°: 0%

**Own research*

[38] *http://www.estif.org/solarkeymarknew/, 23. Oct. 2014*

5.1.2.3. Concentrating collectors (Fresnel)

Concentrating collectors such as the Fresnel collectors are able to achieve higher temperature ranges and therefore provide the opportunity to generate steam and to integrate solar thermal energy into industrial processes at supply level. So far this technology remains at an early market stage with only a few projects deployed worldwide. Fresnel collectors currently show the best price/performance ratio among concentrating collectors for process heat applications. This study considers the following technical parameters:

Table 10: Technical data for linear Fresnel collectors*

Type:	linear Fresnel collector
Size:	
Primary surface area:	22 m²
Heat capacity:	
Specific heat capacity:	257 Ws/(m²K)
Heat losses:	
Simple heat transfer coefficient:	0 W/(m²K)
Quadratic heat transfer coefficient:	0,0004 W/(m²K²)
Optical losses:	
Conversion factor:	63,5%
Incident angle modifier (IAM) for diffuse radiation:	0%
DNI related IAM along pipe:	DNI related IAM across pipe:
0°: 100%	0°: 100%
5°: 96,2%	5°: 104,4%
10°: 93,7%	10°: 100%
15°: 90,7%	15°: 103,4%
20°: 86,7%	20°: 99,6%
25°: 82,1%	25°: 101,5%
30°: 76,8%	30°: 99,8%
35°: 71,5%	35°: 97%
40°: 64%	40°: 95,6%
45°: 56%	45°: 95,35%
50°: 48,5%	50°: 95,1%
55°: 39,5%	55°: 86%
60°: 31,1%	60°: 78,4%
65°: 22,5%	65°: 65%
70°: 14,1%	70°: 55,3%
75°: 7%	75°: 43%
80°: 2,2%	80°: 30%
85°: 0%	85°: 16%
90°: 0%	90°: 7,5%

**Own research*

5.1.2.4. Long-term performance

As with any technical system, the efficiency of the solar collector decreases very slightly year by year due to sullage inside the pipes, physical and chemical changes of surfaces, etc. This decrease is negligible for short periods like three or five years, but for a 20-year calculation this degradation amounts to 0.5% per year.

5.2. Economic boundary conditions

5.2.1. Energy costs

The energy costs used for the economic calculations are based on the following table:

Table 11: Energy price assumptions of the study*

Energy/source	Gross price (TD/kWh)	Energy content	
Natural gas **STEG (May 2014)**	0,038	10,42	kWh/m³
Liquid petroleum gas **Ministère de l'industrie et de la technologie (2014)**	0,086	12860,568	kWh/ton
Domestic fuel oil	0,125	10	kWh/l
Heavy fuel oil **Ministère de l'industrie et de la technologie (2014)**	0,045	11383,812	kWh/ton
Electricity (low voltage) **STEG (May 2014)**	0,3481	1	kWh
Electricity (medium voltage) **STEG (May 2014)**	0,19706	1	kWh

** STEG 2014, MIT 2014, own research*

Based on the 2014 situation, it was assumed that the energy price increase would happen within two periods: the first six years in order to fulfil the political goal of phasing out energy subsidies, and the second phase during the following years, when energy prices remain stable slightly above the general inflation rate. This rate is used identically for all energy types and will have an effect on the calculation of the sensitivities in two steps.

With the recent drop of oil prices, however, the pressure of phasing out subsidies has been lifted and short-term energy price increases have become less likely.

Table 12: Assumptions of the study regarding energy price development

Years 1-6	10%
Years 7-20	5%

5.2.2. Solar system costs and O&M costs

The solar system costs are calculated based on specific costs in the TD/m² collector area. The prices vary, depending on the plant size. The following table shows the assumed prices for different plant sizes. For plant sizes between the ones mentioned, linear interpolation is applied.

Table 13: Solar thermal system price assumptions[39]

Technology	Plant size/m²	Spec. Price/ (TD/m²)
Flat plate (incl. import tax ≥ 1000 m²)	100	1000
	1000	840
	5000	630
Vacuum tube (incl. import tax)	100	1365
	1000	1050
	5000	787,5
Concentrating collectors (Fresnel[40]) (incl. import tax)	500	1924
	2000	1082
	10000	902

For the storage tanks, three different types are integrated in the plants:

Table 14: Storage tank price assumptions[41]

Tank type	Costs/ TD per litre
DHW (glazed), incl. import tax	2,81
Buffer tank	1,48
Buffer tank (high pressure), import incl. import tax	2,96

In the case of DHW, existing tanks are partially used as solar preheating tanks and generate no additional investment cost, as they already form a part of the conventional system.

The annual costs for operation and maintenance are set at 1% of the investment for non-concentrating solar systems and 2% for concentrating systems, because the later need more maintenance, regular cleaning and engineering support.

5.2.3. Subsidies for the solar plant

In the tertiary sector, the subsidy is 300 TD/m² of which 50% is paid by the FTE and 50% by a UNEP facility. This arrangement is limited to 55% of the investment, but the limit does not apply because the subsidy is always less than 55% of the investment.

In the industrial sector, the subsidy is 150 TD/m². It is limited to 30% of the investment. This limit does not apply, however, because the subsidy is always less than 30% of the investment.

[39] *Price research according to experts from Tunisia and Germany*

[40] *With Fresnel collectors, it is possible either to produce pressurized hot water or steam inside the collector. The steam system needs additional equipment such as a steam drum. This results in an additional charge (+5%) for steam systems. If the industrial process needs hot air, for example for drying, (see case IS 4) a good choice is not to evaporate the water but to use it directly in the air heat exchanger. This strategy makes the Fresnel system simpler, which translates into monetary savings (- 5%).*

[41] *Price research according to experts from Tunisia and Germany*

Excursus: New solar process heat support mechanism (ANME)

A new support mechanism for solar process heat has been proposed by ANME to replace the existing mechanism. The new mechanism is composed of the following components:

Subsidy grant

A subsidy grant of TD 150/m² collector area is paid up front, which can be deducted from equity (no change to current mechanism)

Equity

30% of equity is expected

Soft loans

The FTE provides a soft loan of 25% of the total investment at 2%/year credit rate for 15 years. The first 5 years are a grace period.

A conventional credit for the remaining 45% of the investment costs. This credit is given for 10 years at an interest rate of 5%/year, which is a subsidy of 2% compared to conventional credits of 7%.

Additional income

Additional income for the investor can be generated by a 25% payback payment of the fuel subsidies saved by ANME because conventional fuel (oil/gas) is not needed.

5.2.4. Other economic calculation parameters

For all solar plants, the operational period is typically assumed to be at least 20 years.

The interest rate for costing purposes (capital interest rate) is set at 6% for investments in the tertiary sector and 8% in the industrial sector. Strictly speaking, only an internal rate of return (IRR) higher than the capital interest rate is economically viable. When considering either equity or lending money from another source, this would mean that any value below the internal capital interest rate would improve the economics of the projects; meanwhile higher values would have negative effects.

It is important to bear in mind that the inflation rate in Tunisia has been between 2.8 and 6.2% in the last twenty years and is currently around 5% (2014). Nevertheless, since the International Monetary Fund (IMF) projects it to come down to 4% until 2017, 4.3% was chosen as long term assumption for the report.[42] Although the inflation rate is not used for the calculations, in particular the IRR has to be reviewed in respect to the inflation rate. The IRR has to be as high as or higher than the inflation rate.

[42] *Projections for 2014 – 2018 in World economic outlook (IMF): IMF Country Report No. 14/362 , December 2014 19 Jan. 2015*

5.3. Methodology

For each case study, the same methodology is applied. The first step is to prepare the system and to execute a series of simulations with the simulation programme T*SOL. Then, based on the results, the economic calculations are delivered in a standardized Excel sheet.

Table 15: Overview of parameters for simulations and economic calculations[43]

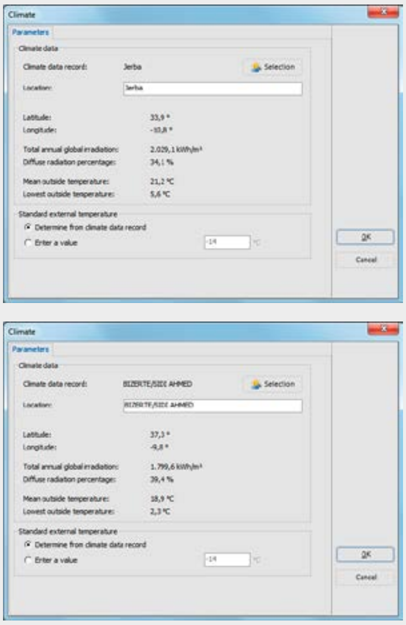
Simulation with T*SOL	Economic calculations with MS-Excel
System parameterisation: • Location • Heat demand • Hydraulic scheme • Collector type • Fuel and boiler • Piping	Basic parameters: • Interest on capital • Increase rates • Subsidy rate • Specific costs of components • Specific costs of fuels • Operation and maintenance percentage
Simulation series: • Variation of collector area • Variation of tank volume (if tank exists in scheme)	Economic calculations: For each system according to the T*SOL variations the following results are calculated: • Investments • Annual costs • Present values • Net present value • Levelized heating costs • Dynamic payback period • Static payback period
Simulation results: • Solar efficiency • Solar fraction • Auxiliary heating energy • Solar energy savings	Choice of most economically viable tank volume for each collector area Choice of most economic viable size of collector area Sensitivity analysis for • Subsidy rate • Fuel price • Energy price increase rate

5.3.1. Locations

Climate data is based on the Meteonorm 7 database (period 1986-2005), which provides location-specific climate data.

Two locations have been chosen for the case studies of the tertiary sector. Jerba is a very popular tourist region and has been chosen for the hotel case study. The other case studies are simulated for the Tunis region, represented by the data set for Bizerte/Sidi Ahmed. For all cases, global horizontal irradiation data (GHI) was used.

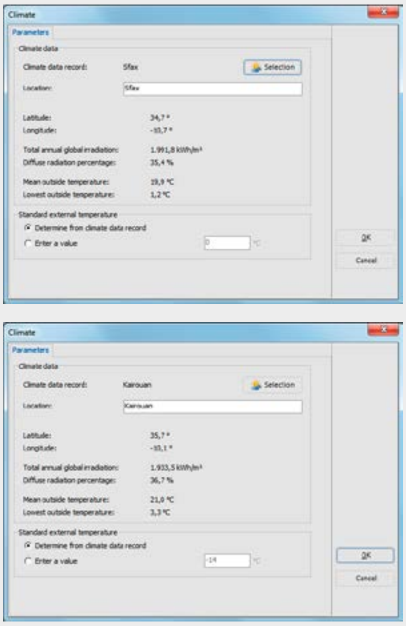
Figure 15:
Data sets for tertiary sector case studies



Three locations have been chosen for the case studies of the industrial sector. The Tunis region (Bizerte/Sidi Ahmed on the north coast) has been used for parameter variations. As part of the sensitivity analysis, Sfax on the south-eastern coast and the inland location of Kairouan have been used.

[43] *For definitions and formulas, please consult Annex 9.1*

Figure 16:
Data sets for industrial sector case studies



5.3.2. System parameterization

The initial point of each case study is the given demand. From the demand type, an appropriate T*SOL hydraulic scheme is chosen (see 5.1). The temperature level of the demand determines which collector types are used for the case study.

Boiler efficiency and fuel type is given for each case.

The system is parameterized with adequate values for the collector loop and tank insulation. For more details, see attached T*SOL reports in the annex.

5.3.3. Simulation series

Simulations in this study vary the collector field area (system size) in order to find the most economical setting for the solar thermal plant (smaller solar fractions versus higher ones). This way smaller solar fractions (usually higher specific energy efficiencies) are compared to the economic performance of higher solar fractions.

Using an iterative approach, each collector size is then matched with the respective buffer tank volume (if the system relies on a solar buffer tank).

The results of each simulation are the solar efficiency, the solar fraction and the auxiliary heating energy. The solar efficiency and the solar fraction mainly help to rate system quality. For the economic calculations, auxiliary heating energy is used.

Comparing systems with and without solar systems, the difference lies in the solar contribution to the heating demand (solar yield). Divided by the boiler efficiency, the result is the saved energy via the solar contribution. This value is used to calculate the saved fuel costs, which is the base of the further economic analysis.

5.3.4. Basic parameters of economic analysis

For the calculation of costs and present values, the economic boundary conditions have to be defined for each case study:

- Area-specific system costs:
  These include collector costs and all other costs related to the solar system. They depend on collector type and size of the collector field.

- Specific tank costs:
  These are applied to additional tank volume, which is installed to increase the solar efficiency.

- Operation and maintenance costs (O&M):
  Given in percentage of total investment

- Subsidy rate:
  Related to collector area

- Period under consideration (lifespan)

- Interest on capital

- Energy-specific fuel price (TD/kWh):
  This allows a better comparison between different fuel types.

- Increase rate for O&M

- Increase rate for energy costs

- Degradation: This rate shows the decrease in the annual solar yield year by year.

5.3.5. Economic calculations

For each simulation there is a row in the Excel sheet with the economic calculations:

Figure 17: Examples for output data sheets

Simulation Data					
#	Count of Collectors	Tank Volume [l]	Efficiency [%]	Solar Fraction [%]	Boiler Energy [kWh]
1	100	10000	62,551	13,289	935330
2	100	15000	62,557	13,313	935060
3	100	20000	62,576	13,342	934730
4	100	25000	62,54	13,348	934750
5	100	30000	62,485	13,348	934730
6	100	35000	62,472	13,362	934530
7	100	40000	62,426	13,363	934510
8	100	45000	62,27	13,334	934830
9	100	50000	62,266	13,342	934760
37	200	10000	61,381	25,979	797920

Investments					Subsidy
Collector Area	Extra Tank Volume [m³]	Collector Costs [TD]	Tank Costs [TD]	Total Invest Costs [TD]	Subsidy [TD]
100	0	136500	0	136500	30000
100	5	136500	14050	150550	30000
100	10	136500	28100	164600	30000
100	15	136500	42150	178650	30000
100	20	136500	56200	192700	30000
100	25	136500	70250	206750	30000
100	30	136500	84300	220800	30000
100	35	136500	98350	234850	30000
100	40	136500	112400	248900	30000
200	0	266000	0	266000	60000

Annual Costs					
OMC [TD]	Pump Energy Costs [TD]	Solar Yield [kWh]	Specific Solar Yield [kWh/m²]	Solar Savings [kWh]	Solar Savings [TD]
1365	59	143345	1433	162892	14009
1506	59	143615	1436	163199	14035
1646	59	143945	1439	163574	14067
1787	59	143925	1439	163551	14065
1927	59	143945	1439	163574	14067
2068	59	144145	1441	163801	14087
2208	59	144165	1442	163824	14089
2349	59	143845	1438	163460	14058
2489	59	143915	1439	163540	14064
2660	118	280755	1404	319040	27437

Present Values				Dynamic Economic Analysis						Static Payback Periods	
OMC [TD]	Pump [TD]	Savings [TD]	Total PV [TD]	LHC [TD/MWh]	Dynamized LHC [TD/MWh]	NPV (added) [TD]	NPV [TD]	IRR [%]	DPP [y]	SPP (IoC=0, prices increase) [y]	SPP (IoC=0, no increase) [y]
22184	1285	291419	267951	82	38	161451	161451	17,6	7,9	6,4	8,5
24467	1285	291968	266216	92	43	145666	145666	15,6	8,9	7,1	9,7
26751	1285	292639	264604	102	48	130004	130004	14,0	10,0	7,7	10,9
29034	1285	292599	262280	113	53	113630	113630	12,5	11,1	8,4	12,2
31317	1285	292639	260037	123	57	97337	97337	11,3	12,3	9,0	13,5
33601	1285	293046	258160	133	62	81410	81410	10,2	13,4	9,7	14,8

The calculations are executed according to economic boundary conditions. The calculations are done dynamically with respect to the interest on capital (IoC).[44]

The investment is considered economically viable if the net present value (NPV) is positive.[45] Equivalent conditions are: The internal rate of return (IRR)[46] is higher than the IoC; the dynamic payback period (DPP) is lower than the considered investment period. The payback period is additionally calculated statically (SPP), as this is a common method in Tunisia.

[44] *The interest on capital or interest rate is the rate at which interest is paid by borrowers (debtors) for the use of money that they borrow from lenders (creditors). For more information, please consult http://en.wikipedia.org/wiki/Interest_rate, 08 March 2015*

[45] *In financial terms, the net present value (NPV) is defined as the sum of the present values (PVs) of incoming and outgoing cash flows over a period of time; for more information, please consult: http://en.wikipedia.org/wiki/Net_present_value 08 March 2015*

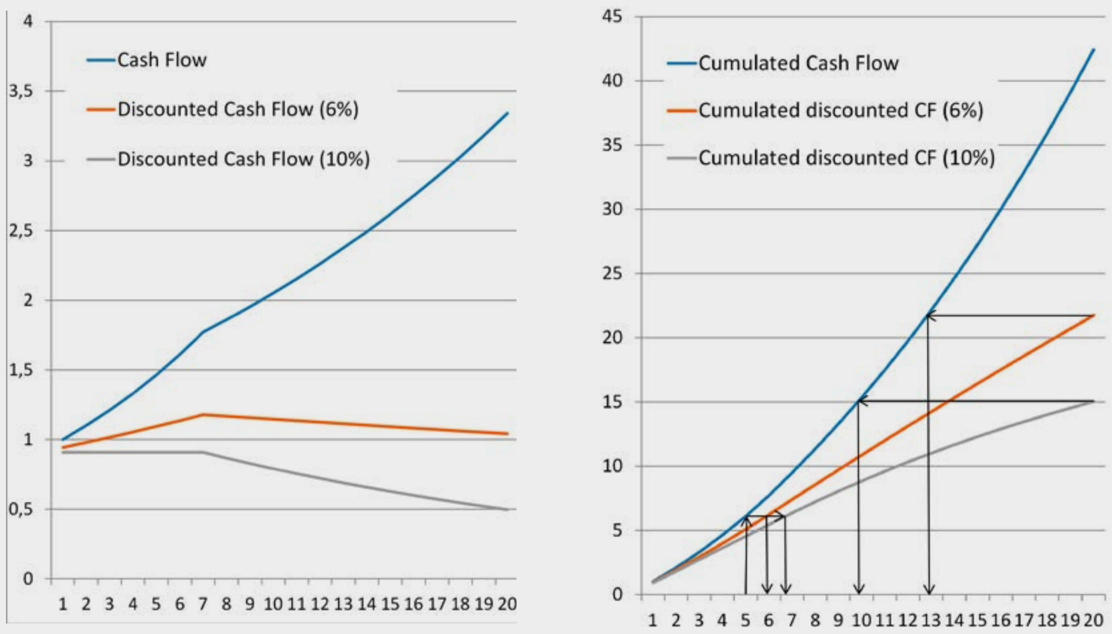
[46] *The internal rate of return on an investment or project is the "annualised effective compounded return rate" or rate of return that makes the net present value (NPV as NET*1/(1+IRR)^year) of all cash flows (both positive and negative) from a particular investment equal to zero. It can also be defined as the discount rate at which the present value of all future cash flow is equal to the initial investment, or in other words, the rate at which an investment breaks even. For more information, please consult: http://en.wikipedia.org/wiki/Internal_rate_of_return#Definition, 08 March 2015*

Excursus: Static versus dynamic payback period

Two principal methods to analyze the economics of an investment are used in practice: static and dynamic considerations. Static economic analysis compares only yearly averaged savings with the corresponding costs and does not consider the influence of the time of payments in a correct manner, e.g. does not consider inflationary effects. The longer the investment period, the more the two values differ. As investment for solar systems shows long lifetimes (in the range of at least 20 to 25 years), preferably the method of dynamic economic analysis should be applied, which fully takes into account the importance of the time when payments occur.[47] Nevertheless, since static payback calculation is more common in Tunisia, most charts use the static calculation and dynamic payback periods can only be reviewed in the tables.

With each year the value of savings becomes less if dynamic cash flow calculations (brown and grey lines) are taken into account. After year six the price increase for energy becomes less (5%) and thus the value of energy savings with a solar system becomes less valuable. The cumulated values show that the difference of static (blue) and dynamic (brown/grey) is not very significant for the first years; over 20 years, payback periods differ between 13 years (static) and 20 years (dynamic/brown line 6% discount rate) or 10 years (static) to 20 years (dynamic/grey line).

Figure 18:
Example of the effects of dynamic and static cash flow calculations with 10% and 5% energy price increase on a yearly (left) and cumulated (right) basis



5.3.5.1. Tank optimization

If the thermal consumers or processes cannot immediately utilize the solar yield, the solar yield is lost as "solar heat losses". To avoid this, a solar storage tank can be used. The effect is an increase in capacity for heat storage. This can be done either in several smaller tanks for one or more days, or in very large seasonal tanks for several months. In the calculations, the size of the tank is only limited by tank costs. This means that for each size of the collector array, it has to be proven whether a larger tank volume generates enough additional solar yield to pay back additional tank costs.

The net present value of an investment is an indicator of the economic viability. Each collector area (system size) thus provides differing levels of profitability for

[47] *http://nesa1.uni-siegen.de/wwwextern/idea/keytopic/14.htm, 06 March 2015*

varying tank volumes. The following table shows the calculation of the most appropriate tank volume for different collector areas. Each collector area has an economical maximum tank volume as defined by the NPV (orange-marked cell). On this basis, the tank volume with the highest capital value is chosen for the corresponding collector area.

The existing domestic hot water system provides hot water tanks that are heated by a conventional heating system. For this study, it is assumed that we can use two thirds of the already existing volume as solar buffer volume, for which no additional costs arise. The remaining third part is big enough because the inlet is mostly solar preheated.

5.3.5.2. Economic results

After tank optimization, the main results of the chosen variants are gathered in one table:[48]

5.3.6. Choice of basic system

The table above allows the most economically viable size of collector field to be chosen under the given boundary conditions (best system). In general, increasing the size of the collector array leads to a higher solar fraction and higher fuel savings, but also to decreasing system efficiency. This reduces economic viability. However, if the specific collector costs (TD/m²) decrease with bigger system sizes (economies of scale) this effect might be compensated. For the solar yield and economic simulations made in this study, the following rule is applied:

- Minimize the static payback period if it is more than five years to select the best-cases.
- If more than one possibility remain, choose the largest system still complying with the payback assumption as it offers the greatest investment options.

Table 16: Example for tank optimization data sheet

NPV [TD*1000]	100 m²	250 m²	275 m²	300 m²	400 m²	500 m²	600 m²	700 m²	800 m²	900 m²	1000 m²
0 m³	210	437	468	498	596	674	713	725	697	672	636
5 m³	196	436	469	501	609	707	765	814	833	821	776
10 m³	181	429	465	499	612	721	796	863	910	924	925
15 m³	165	419	456	491	609	723	810	889	950	976	1001
20 m³	150	406	443	480	599	716	805	900	972	1008	1042
25 m³	134	391	429	466	587	705	797	897	981	1025	1066
30 m³	119	376	414	451	572	690	783	885	977	1030	1077
35 m³	103	361	398	435	556	673	766	869	965	1026	1079
40 m³	87	345	382	419	539	655	746	848	945	1013	1072
Maximum	210	437	469	501	612	723	810	900	981	1030	1079

48 *Table 16 (tank optimization) is thereby transformed into the first two columns of table 17.*

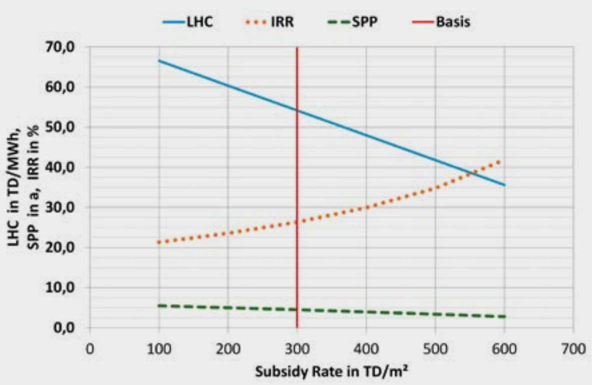
Table 17: Example for economic best-case scenarios for different system sizes

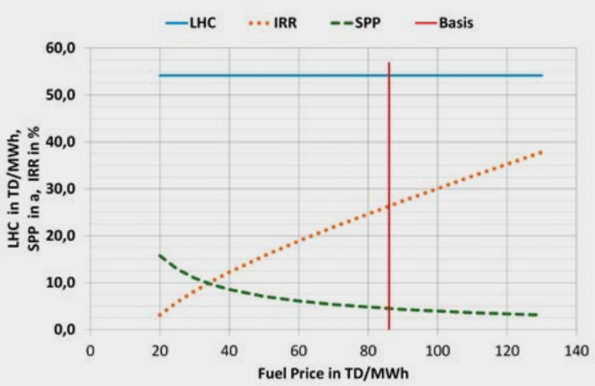
Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
100	0	1463	54,2	209.973	26,3	5,2	4,5
200	0	1340	57,8	373.746	24,9	5,5	4,7
300	5	1258	63,9	500.850	22,7	6,1	5,2
400	10	1193	67,9	612.139	21,4	6,5	5,4
500	15	1150	70,1	723.184	20,8	6,7	5,6
600	15	1084	71,3	809.865	20,5	6,8	5,6
700	20	1048	73,0	900.439	20,1	6,9	5,8
800	25	1013	74,5	980.816	19,7	7,1	5,9
900	30	966	76,8	1.029.723	19,1	7,3	6,0
1000	35	926	78,6	1.079.353	18,7	7,4	6,1

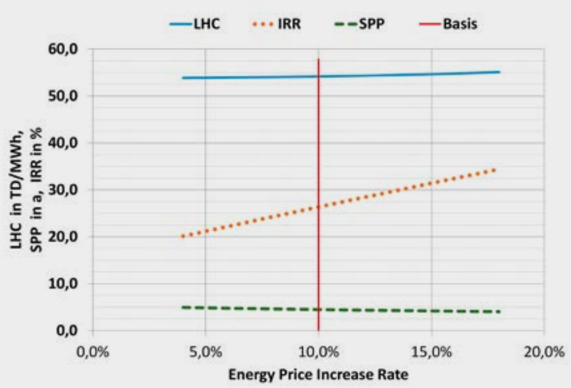
This table allows a discussion of the range of economic viabilities for this case study.

- For the best system (optimized economic setting for collector area and tank volume, table 17) a sensitivity analysis is executed.

Figure(s) 19:
Examples of best-case sensitivity analysis





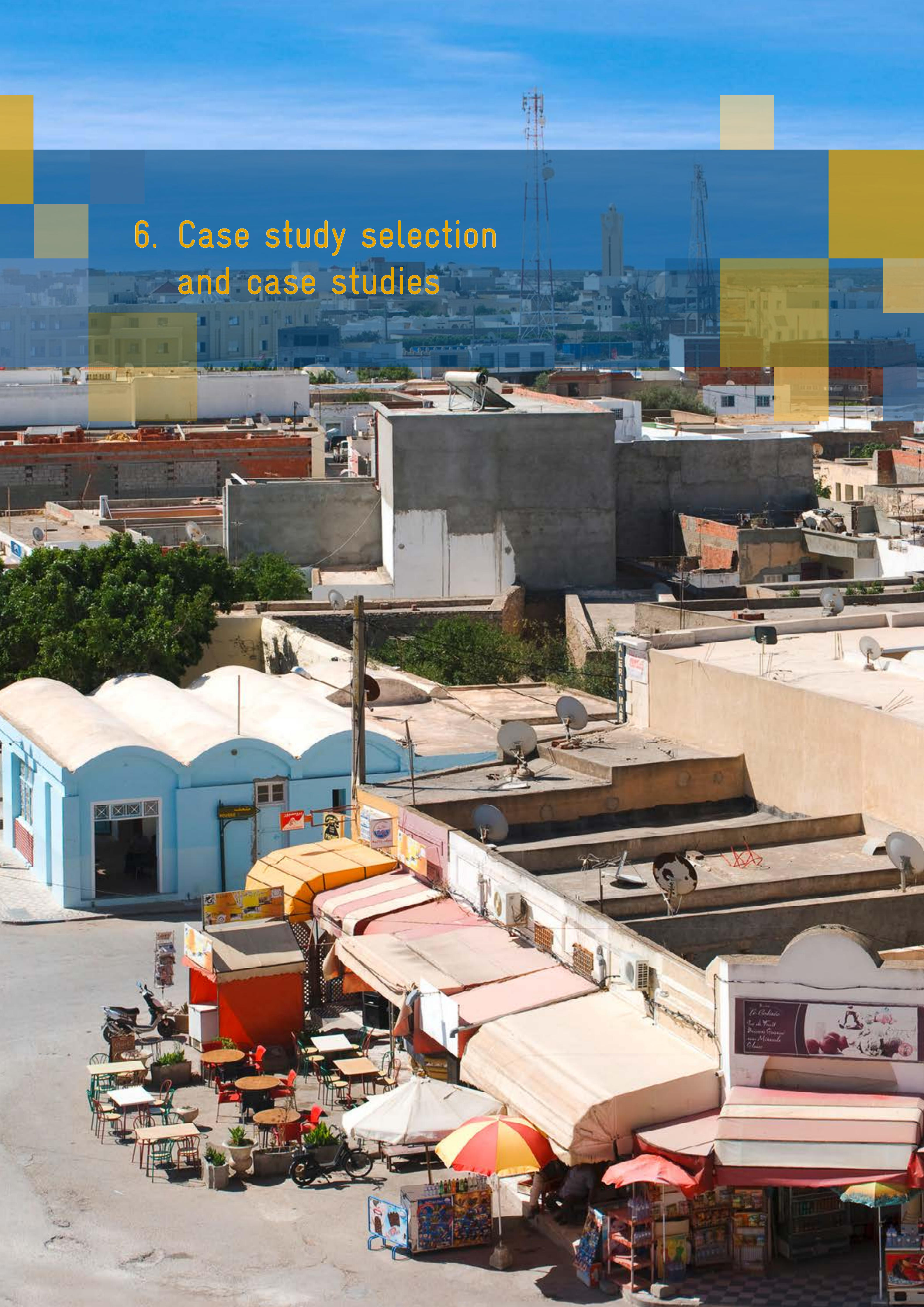


5.3.7. Sensitivity analysis

Sensitivity calculations allow the identification of factors that have the most influence on the profitability of investments. The profitability of solar thermal systems is largely determined by i) investment costs per m² (depending on specific system costs and subsidy scheme) and ii) by the cost of the respective fossil fuels to replace (fuel price savings). In order to evaluate current and future market potential, this study examines the effects of adjusting a) the subsidy rate (TD/m²) (and thus indirectly the specific system costs), b) the fuel price (TD/MWh) and c) the energy price increase rate (in%) for each "best-case". A summary chart then presents the effects on levelized heat costs,[49] the internal rate of return and static payback period. The reference value (base case) used for the calculations is marked by a vertical line.

[49] *Levelized Heat Costs – LHC = annuity of all costs / solar yield in TD/MWh*

6. Case study selection and case studies



This chapter gives a general overview of relevant cases in the tertiary and industrial sectors. It can be used as a basis to evaluate existing and upcoming market opportunities. It distinguishes between the identified segments in the tertiary and industrial sector. The case studies have been chosen in a way that the consumer profile (energy demand) represents a typical example of the respective market segment.

6.1. Tertiary sector

In the tertiary sector, hotels have the highest energy needs. So far there are around 30 hotels equipped with solar thermal installations that have benefitted from the PROSOL Tertiary programme. Most hotels are situated near the coast in two major touristic areas: in the area between Hammamet and Sousse all along the coast and in the southern part of Tunisia, on the island of Jerba. These two locations are also interesting for the study since along the coast, most cities have access to the natural gas grid, whereas Jerba at the moment has only LPG or heating oil as primary energy. On Jerba the solar irradiation is approximately 10% higher than in the other regions.

The tertiary sector is also represented by hospitals, sports facilities and residences for certain groups of people, such as boarding schools for students or residences for the military or the police. All these kind of buildings normally have one central heating station which makes it possible to easily integrate solar energy, provided that the buildings are not organized in distributed single buildings (e.g. barracks).

To investigate the potential of solar energy at different temperature levels, cases are presented for heating of pool water (<30°C), domestic hot water (<60°C) and space heating of buildings during winter.

Table 18: Overview of the number of potential cases for the tertiary sector

<table>
<tr><th>Category</th><th colspan="2"></th><th>Number of institutions</th><th>Source of information (web link)</th></tr>
<tr><td rowspan="3">Hospitals</td><td colspan="2">Public health centres</td><td>21</td><td>http://www.santeTunisie.rns.tn/fr/index.php?option=com_content&view=article&id=269&Itemid=154</td></tr>
<tr><td colspan="2">Regional hospitals</td><td>33</td><td></td></tr>
<tr><td colspan="2">District hospitals</td><td>109</td><td></td></tr>
<tr><td>Private hospitals
Private clinics</td><td colspan="2"></td><td>75</td><td>http://www.santeTunisie.rns.tn/fr/index.php?option=com_content&view=article&id=269&Itemid=154</td></tr>
<tr><td>Hotels</td><td colspan="2"></td><td>880 (average)</td><td>http://www.tourisme.gov.tn</td></tr>
<tr><td rowspan="4">Residences for military, police, students, …..</td><td colspan="2">Military</td><td></td><td>No information available</td></tr>
<tr><td rowspan="2">Students</td><td>Public</td><td>39</td><td>http://www.etudiant.tn/ar/home/index.php?pe=fbublic_4_18_1</td></tr>
<tr><td>Private</td><td>43</td><td>http://edu.marhba.com/foyer-Tunisie/foyer-prive-Tunisie</td></tr>
<tr><td colspan="2">Police</td><td></td><td>No information available</td></tr>
<tr><td>Public baths[50]</td><td colspan="2"></td><td>950-1000</td><td>No information available</td></tr>
</table>

[50] *Estimation*

Table 19: Case study selection type tertiary sector

Sector	ID	Project type	Solar-supported demand	T*SOL system type	Collector technology
Tertiary sector	TS1	Hotel	Hot water (DHW) 25-85°C	A 2	Flat plate, tubes
Tertiary sector	TS2	Hospital	Hot water and space heating 25-85°C	A 4	Flat plate, tubes
Tertiary sector	TS3	Public indoor pool	Pool heating 25-60°C	B 6.2	Flat plate
Tertiary sector	TS4	Collective residence	Hot water (DHW) 25-85°C	A 2	Flat plate, tubes

In hotels in tourism areas, the peak load occurs during spring and summer when many foreign visitors and Tunisians come to the coast, whereas hospitals are used throughout the year. In residences holidays can also have an influence on the energy demand.

The number of relevant tertiary institutions is fairly well known in Tunisia, since data is available for most segments in Tunisia.

The data for the cases selected in the study was drawn from projects where measurements and audits had been carried out, as well as from the experience of local experts. These were then verified and considered to represent typical examples of the respective building type.

To represent these load profiles, temperature levels and applications, the following cases were defined in the study.

6.1.1. TS 1 – Hot water for hotels

6.1.1.1. Description of the object

In this case study, a typical hotel has two characteristics: a capacity of 570 rooms and a coastal location. The yearly hot water demand is 22,000 m^3 at 55°C and is provided by several gas boilers. The existing heating system is described in the following table:

Table 20: Basic assumptions, hotel case (TS1)

Basic data	
Heating system	Natural gas
Efficiency	85%
Thermal capacity installed/boiler (kW)	6280
Number of boilers	5
Temperature range (°C)	54°C-80°C
Age of boiler in years	more than 15 years
With circulation	Yes
One-way length of piping system	190 m
Subsector	Hotel
Climate zone	Coast

The monthly and daily profiles are well known, as an existing energy audit provides measurements which had been taken for a similar hotel.

Table 21: DHW demand in m³ and percent, hotel case (TS1)

Profile in % of the annual hot water demand (m³)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total
1.080	957	1.834	1.694	2.616	2.452	2.624	2.241	2.197	2.299	1.105	960	22.059
4,9%	4,3%	8,3%	7,7%	11,9%	11,1%	11,9%	10,2%	10,0%	10,4%	5,0%	4,4%	100%

Table 22: Weekly and daily heat demand, hotel case (TS1)

Profile in % of the daily demand																									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	total
Mon	1,2	1,2	1,3	1,3	1,2	1,1	2,8	6,7	8,1	9,3	9,0	8,3	5,8	4,7	6,5	7,4	6,1	3,5	3,1	3,7	2,8	1,9	1,5	1,5	100,0
Thu	2,0	1,6	1,2	1,1	1,7	3,0	3,4	6,9	9,9	7,0	4,9	4,7	4,7	5,3	6,0	6,4	5,1	4,1	4,5	5,4	4,0	2,6	2,2	2,4	100,0
Wed	1,7	1,4	1,1	0,9	1,3	2,1	3,7	7,5	7,0	7,5	8,0	7,9	5,0	4,7	6,6	7,2	5,9	3,2	3,3	4,6	3,0	2,2	2,1	2,0	100,0
Thu	1,7	1,4	1,1	0,9	1,3	2,1	3,7	7,5	7,0	7,5	8,0	7,9	5,0	4,7	6,6	7,2	5,9	3,2	3,3	4,6	3,0	2,2	2,1	2,0	100,0
Fri	1,7	1,4	1,1	0,9	1,3	2,1	3,7	7,5	7,0	7,5	8,0	7,9	5,0	4,7	6,6	7,2	5,9	3,2	3,3	4,6	3,0	2,2	2,1	2,0	100,0
Sat	1,7	1,4	1,2	1,0	1,9	3,0	3,5	8,4	7,4	7,9	8,5	8,2	5,5	3,8	3,8	3,6	3,9	3,6	4,0	4,8	5,0	3,5	2,3	1,9	100,0
Sun	2,3	1,6	1,4	1,2	1,2	1,4	2,3	6,0	10,7	6,9	6,0	5,2	5,3	5,1	4,8	4,7	5,6	5,0	4,8	5,8	4,3	3,2	2,6	2,5	100,0

The T*SOL simulation employs the following profile: The dark blue bars represent the amount of energy needed for providing domestic hot water; the orange bars show how much energy is lost in the hot water distribution network. This quantity is necessary to guarantee the comfort of the hotel guests. This profile represents a typical hotel domestic hot water demand.

6.1.1.2. Results for TS1

Three different cases were simulated for the locations Jerba and Tunis. The fuel source in Tunis is natural gas whereas in Jerba LPG is used. The Jerba case study applies to both flat plate collectors (FPC) and vacuum tube collectors (CPC).

Figure 20:
Monthly heat demand and losses, hotel case (TS1)

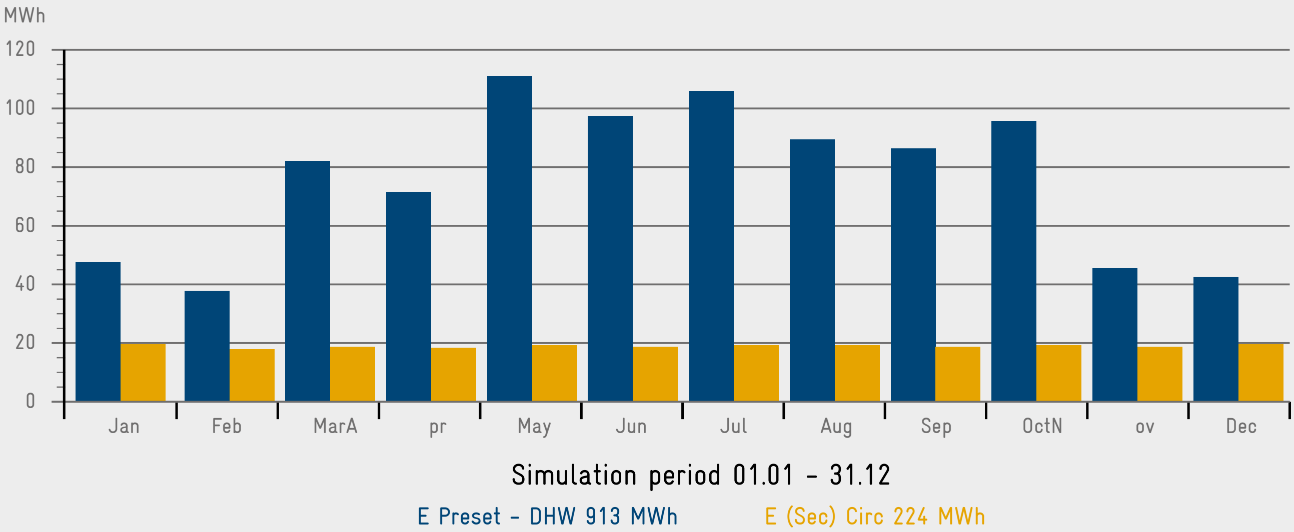


Table 23a: Hotel case overview

	Case I	Case II	Case III
Collector type	FPC	CPC	FPC
Location	Jerba	Jerba	Tunis
Fossil fuel replaced	LPG	LPG	NG

Table 23: Best-case comparison of economic data in Jerba and Tunis, hotel case (TS1)

Location	Type	Fuel	Area [m²]	LHC [TD/MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
Jerba	FPC	LPG	100	54,2	209.973	26,3	5,2	4,5
Jerba	CPC	LPG	400	80,1	611.876	18,1	7,7	6,3
Tunis	FPC	NG	100	61,4	28.409	9,7	14,0	9,9

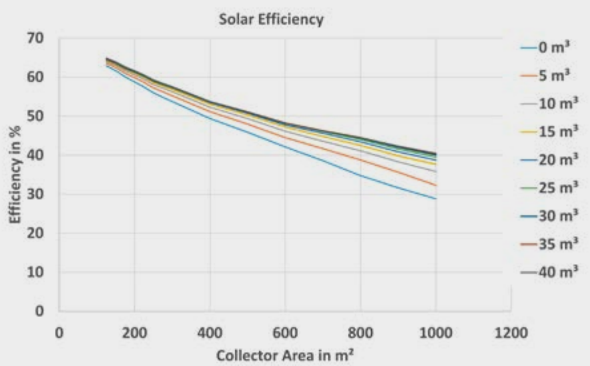
For each of the three cases a tank optimization was simulated, though the most economic scenarios (best-cases) do not ask for extra tank volume (this means that the solar system can be integrated into the existing tank volume of 15 m³). In the appendix, the results of all simulations and calculations are listed in detail.

For the temperature level of 54°C to 80°C applied in this case, FPC are significantly more efficient (>60%) for small plant sizes than for large plants (<40%). Nevertheless, small systems achieve low solar fractions (15%) of the overall energy yield, whereas large FPC plants can reach a solar fraction of up to 85%.

The reason for the excellent system efficiency is the high conformity over the year between hot water demand and solar irradiation i.e. low demand in winter and high demand in summer time. For small plants, the temperature difference between solar loop and ambience is small and there is no surplus of solar energy in summer time.

In the case of vacuum tube collectors, the efficiency is quite stable – up to 400 m² – and reaches a solar fraction of close to 50%. Very large systems can yield a solar fraction of nearly 100%.

Figure 21:
Sensitivity analysis between collector area, storage tank size and system efficiency/solar fraction for flat plate collectors, hotel case (TS1)



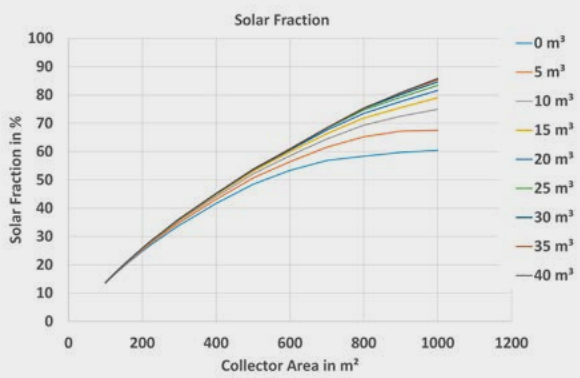
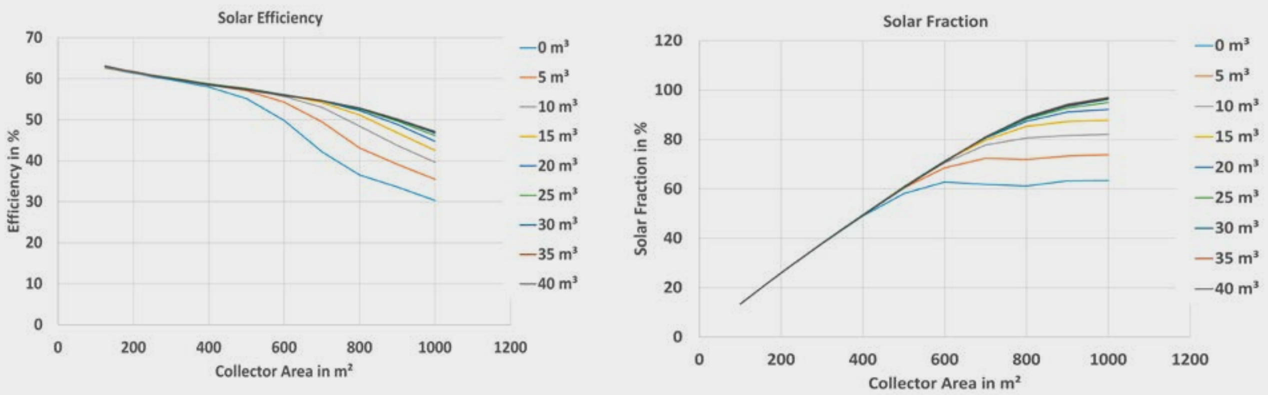


Figure 22:
Sensitivity analysis between collector area, storage tank size and system efficiency/solar fraction for vacuum tube collectors, hotel case (TS1)



Case I: FPC, Jerba

The best-case static payback period for flat plate collectors in Jerba is less than five years (4.5 years).

According to the rules, 200 m² collector size would be the best-case. However, even large plants with 1000 m² reach an SPP of about six years only. In the payback, the investment for the extra tank is included. Though slightly less profitable, the investor can invest more money at highly profitable rates if he accepts slightly lower IRRs. This can prove to be useful, since the evaluation of investment decisions also involves effort and cost. As shown in the following table, the economic tank optimization yields up to 35 m³ extra solar buffer volume.

Case II: CPC, Jerba

The best-case analysis with vacuum tube collectors in Jerba results in a best static payback period of 6.3 years with a collector area in the range of 300 to 500 m², thus making it less economic in comparison to equally sized FPC systems.

However, the main advantage of vacuum tube collectors is a possible system capacity of nearly 100% solar fraction. This means that there is no need for a hot water boiler anymore.

Table 24: Best-case analysis with flat plate collectors, hotel case (TS1)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
100	0	1463	54,2	209.973	26,3	5,2	4,5
200	0	1340	57,8	373.746	24,9	5,5	4,7
300	5	1258	63,9	500.850	22,7	6,1	5,2
400	10	1193	67,9	612.139	21,4	6,5	5,4
500	15	1150	70,1	723.184	20,8	6,7	5,6
600	15	1084	71,3	809.865	20,5	6,8	5,6
700	20	1048	73,0	900.439	20,1	6,9	5,8
800	25	1013	74,5	980.816	19,7	7,1	5,9
900	30	966	76,8	1.029.723	19,1	7,3	6,0
1000	35	926	78,6	1.079.353	18,7	7,4	6,1

If considered in the planning process of new hotels, boilers and LPG tanks might no longer be necessary when using CPC systems. This could increase the economic viability of a CPC solar plant (in comparison to a similarly-sized FPC plant) due to the savings on the conventional heating system, even though it is not further investigated in the study.

Table 25: Maximum net present value (NPV) depending on solar thermal system size and storage capacity system, flat plate collectors (FPC), hotel case (TS1)

NPV [TD*1000]	100 m²	250 m²	275 m²	300 m²	400 m²	500 m²	600 m²	700 m²	800 m²	900 m²	1000 m²
0 m³	210	437	468	498	596	674	713	725	697	672	636
5 m³	196	436	469	501	609	707	765	814	833	821	776
10 m³	181	429	465	499	612	721	796	863	910	924	925
15 m³	165	419	456	491	609	723	810	889	950	976	1001
20 m³	150	406	443	480	599	716	805	900	972	1008	1042
25 m³	134	391	429	466	587	705	797	897	981	1025	1066
30 m³	119	376	414	451	572	690	783	885	977	1030	1077
35 m³	103	361	398	435	556	673	766	869	965	1026	1079
40 m³	87	345	382	419	539	655	746	848	945	1013	1072
Maximum	210	437	469	501	612	723	810	900	981	1030	1079

Table 26: Best-case analysis with vacuum tube collectors, hotel case (TS1)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD /MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
100	0	1440	81,7	162.686	17,7	7,9	6,4
200	0	1398	81,5	316.553	17,8	7,9	6,4
300	0	1365	80,8	467.131	18,0	7,8	6,3
400	0	1332	80,1	611.876	18,1	7,7	6,3
500	5	1309	80,9	745.693	18,0	7,8	6,3
600	15	1287	82,9	863.161	17,5	8,0	6,5
700	20	1247	83,4	970.080	17,4	8,0	6,5
800	25	1193	84,8	1.046.991	17,2	8,1	6,6
900	30	1124	87,3	1.081.486	16,7	8,4	6,7
1000	30	1042	89,7	1.086.210	16,3	8,6	6,9

Table 27: Best-case analysis with flat plate collectors in Tunis area, hotel case (TS1)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
100	0	1291	61,4	28.409	9,7	14,0	9,9
200	0	1185	65,3	42.023	8,9	15,1	10,5
300	0	1087	69,5	42.664	8,0	16,3	11,1
400	0	1004	73,4	35.385	7,3	17,4	11,6
500	5	976	76,6	25.661	6,8	18,5	12,1
600	10	940	79,6	11.002	6,3	19,4	12,5
700	15	915	81,3	360	6,0	20,0	12,7
800	15	869	82,6	-9.414	5,8	20,4	12,9
900	20	838	84,6	-26.869	5,5	21,1	13,2
1000	20	796	85,9	-39.774	5,3	21,6	13,4

Case III: FPC Tunis

Considering the same plants in the Tunis area, the best-case analysis provides significantly worse results. Tunis has a lower irradiation rate than Jerba, and natural gas is considerably cheaper than LPG. The result is a greater economic viability in Jerba in comparison to Tunis. Even the best-case system only provides a less profitable SPP of 10 years.

Sensitivity analysis

As mentioned in chapter 5, the profitability of solar thermal systems is largely determined by investment costs per m² (subsidy scheme) and by the cost of the respective fossil fuels to be replaced (fuel price savings). Cases I-III have shown that solar thermal systems tend to be profitable on Jerba when replacing LPG (SPPs lower than or equal to 5 years, IRRs in the range of 20-25%). However, replacing the less expensive NG in Tunis leads to significantly lower monetary gains per energy savings and does not corresponds to economic expectations. Even the best-case system only provides SPPs of 10 years, which are below investor expectations.

This section presents a sensitivity analysis to evaluate how economic boundary conditions would have to change in order to profitably run solar thermal systems that replace NG in the hotel sector (based on case III, FPC, Tunis).

In Tunisia the majority of investors demand static payback periods of five years or less. Considering the simple equation that economic viability is only given when the SPP is lower than five years, either one of the following events would have to be true:

- subsidy rates of about 700 TD/m² (equals increase of more than 100%)
- energy price increase rate of 40% per year (currently only 10%)
- NG price of around 80 TD/MWh[51] (currently only 38 TD/MWh) while maintaining the energy price increase scenario as defined in 5.2.1

Overall it can also be concluded that a) and c) are the main influencing factors and by their nature absolute preconditions to achieve economic viability (low SPPs). The energy price increase rate also represents an important factor, but since the increase starts from very low levels, its effect over the first five years of operation of the solar plant is limited. However its effect on the IRR is significant.

Figure 23:
Sensitivity analysis of collector subsidy effects on LHC IRR, SPP, Tunis area with flat plate collectors, hotel case (TS1)

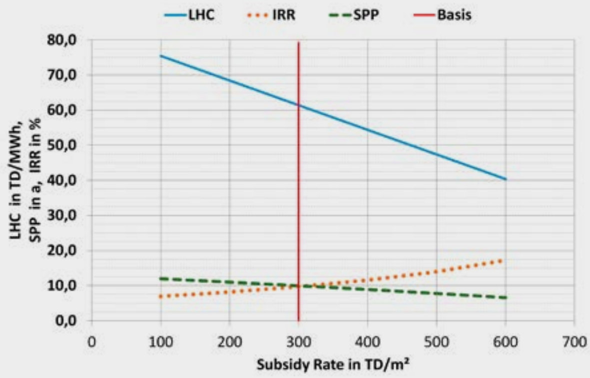


Figure 24:
Sensitivity analysis of absolute fuel price increase effects on LHC, IRR, SPP, Tunis area with flat plate collectors, hotel case (TS1)

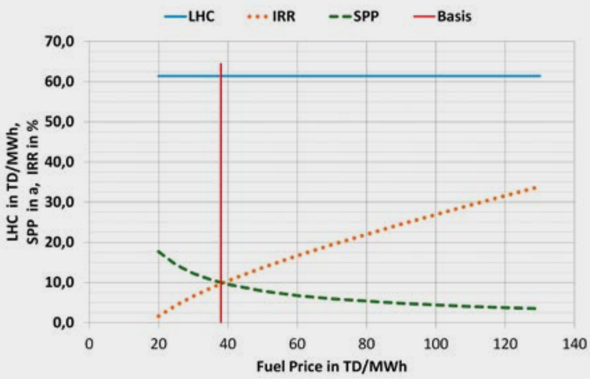
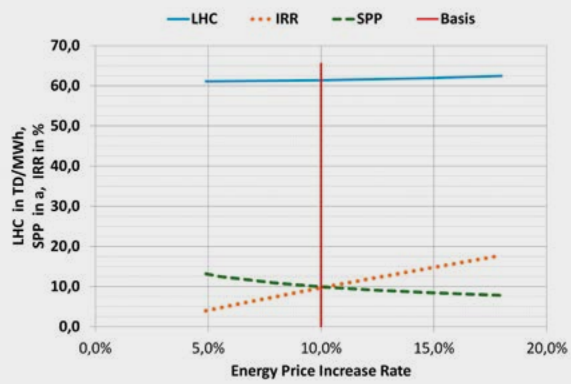


Figure 25:
Sensitivity analysis of relative energy price effects on LHC, IRR, SPP, Tunis area with flat plate collectors, hotel case (TS1)



[51] *This price would be at a similar level as the current LPG price for customers.*

Even doubling the subsidy rate does not lower the SPP to five years or less. This is also valid for the assumption of an even stronger increase of fuel prices than that assumed in this study.

The main impact is the current fuel price. To reach a SPP of five years, the fuel price has to be approximately around 80 TD/MWh. This strong requirement can be reached in the area around Tunis only for significantly more expensive fuels than natural gas.

It has to be noted that demanding SPPs equal to or lower than to five years is a very strong economic requirement for renewable energy systems in general (high initial investment costs, but steady, regularly divided returns over 20 years) and for solar thermal in particular. Often a simple evaluation of the payback period does not represent a comprehensive economic evaluation as the major part of solar revenues (lifetime 20 years) does not enter the equation. This is why it is also interesting to look at other economic indicators (such as IRR, NPV or comparing LHCs).

Already today, all calculated IRRs for case III are positive and above inflation levels. This means that the investment does not lead to a financial loss (also considering the time value of money). However, the calculated NPVs and IRRs have to be seen against the background of other investment opportunities (such as expansion/building of additional hotel rooms or other energy efficiency measures) and thus compared to their economic performance.

These types of evaluation will depend on the investor's perspective and his decision to invest either in long-term or short-term oriented investments.

6.1.2. TS 2 – Hot water and space heating for a hospital

6.1.2.1. Description of the object

For this case study a typical hospital has been defined as one with 250 beds and located at the coast. The annual hot water demand of 11,000 m³ at 60°C is met by two gas boilers. The system is described in the following table:

Table 28: Basic assumptions, hospital case (TS2)

Basic data	
Heating system	Natural gas
Efficiency	89,3%/90,1%
Thermal capacity installed (kW)	600
Number of boilers	2
Age of boiler in years	13
Sector	Public health sector
Subsector	Hospital
Climate zone	La Marsa /coast Z1

The monthly profile is very well known, as an existing energy audit provides measurements taken for a similar hospital.

Table 29: Hot water demand profile in m³ and percent, hospital case (TS2)

Profile in % of the annual hot water demand (m³)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total
1.258	1.102	1.083	950	815	684	688	713	894	943	1.096	1.218	11.444
11,0%	9,6%	9,5%	8,3%	7,1%	6,0%	6,0%	6,2%	7,8%	8,2%	9,6%	10,6%	100,0%

In addition, the hospital needs space heating during winter.

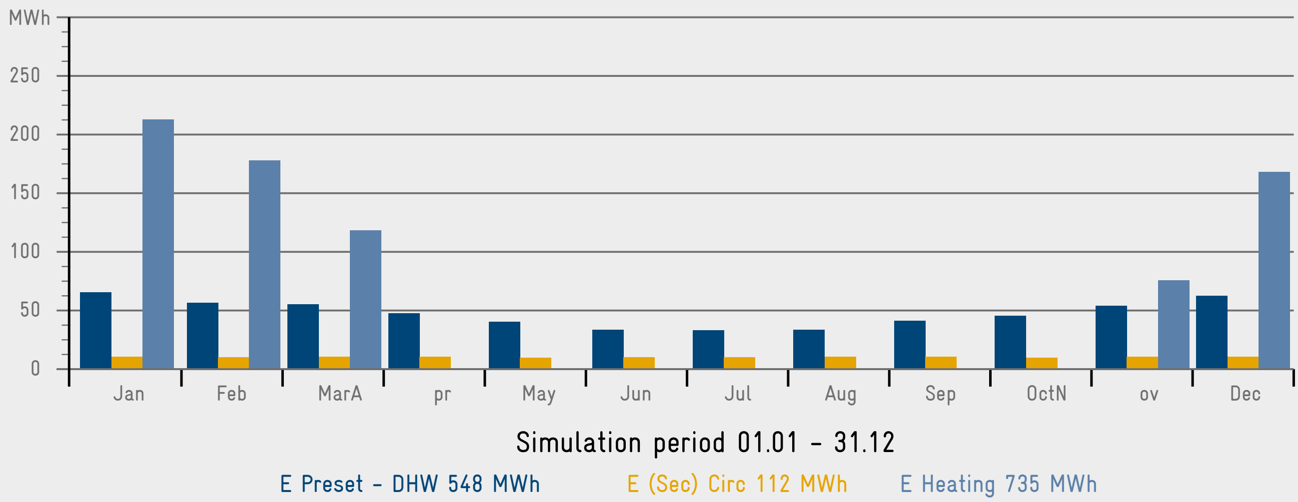
Table 30: Heat demand and information, hospital case (TS2)

Heating demand		
Total heat demand	79.268	Nm³
Total heating area	7.039	m²
Indoor temperature	20-22	°C
Specific internal heat gains	30/40	w/m²

Table 31: Space heating demand profile in m³ and percent, hospital case (TS2)

Profile in % of the annual demand (m³ natural gas)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
19.503	17.999	16.215	0	0	0	0	0	0	0	7.122	18.429	79.268
24,6%	22,7%	20,5%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	9,0%	23,2%	100,0%

Figure 26: Heat and DHC profile for the hospital case (TS2)



The T*SOL simulation results in the following energy profile. The light blue bars show the energy needed for heating, the dark blue bars represent the energy for domestic hot water production and the orange bars represent energy losses in the hot water distribution network.

6.1.2.2. Results for TS2

The focus of this case is a plant in the area of Tunis with natural gas as fuel. For this case, a tank optimization was simulated. The temperature level is similar to the hotel case, but the conformity between demand and solar irradiation is not given and stands in contrast to the needs of space heating.

To illustrate the impact of space heating, one extra simulation is done without space heating. Another case is the situation in Jerba compared to LPG as fuel source. Since CPC collectors have proven to be less economic in the hotel case study (see 6.1.1), no further CPC simulation is conducted for the remaining tertiary cases.[52]

Table 32: Hospital case overview

	Case I	Case II	Case III
Collector type	FPC	FPC	FPC
Location	Tunis	Tunis	Jerba
Fossil fuel replaced	NG	NG	LPG
Demand	DHW + Space Heating	DHW	DHW + Space Heating

For each of the three cases a tank optimization was simulated, though the most economic of the scenarios (best-cases) do not ask for extra tank volume (this means that the solar system can be integrated into the existing tank volume of 10 m³). The tank optimization shows that only plants up to 200 m² have a positive net present value. In these cases, additional tank volume does not increase profitability.

[52] *Results clearly show that at this point FPC offer better economic opportunities for the Tunisian tertiary market.*

Table 33: Maximum net present value (NPV) depending on solar thermal system size and storage capacity system, flat plate collectors (FPC), hospital case (TS2)

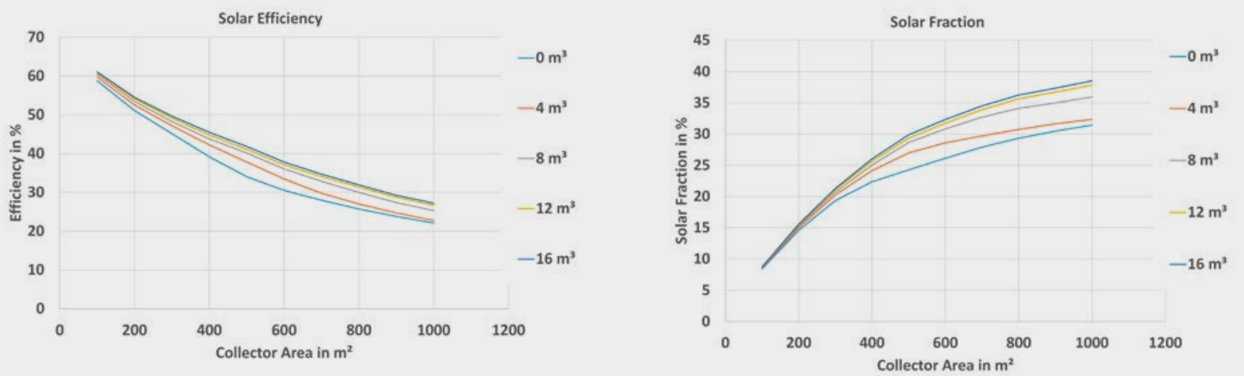
NPV [TD*1000]	100 m²	200 m²	300 m²	400 m²	500 m²	600 m²	700 m²	800 m²	900 m²	1000 m²
0 m³	12	7	-13	-52	-100	-144	-185	-226	-267	-305
4 m³	0	-2	-14	-42	-79	-127	-176	-222	-265	-307
8 m³	-12	-11	-22	-42	-70	-112	-152	-193	-237	-276
12 m³	-24	-22	-30	-48	-74	-113	-150	-188	-230	-267
16 m³	-37	-34	-41	-56	-80	-119	-156	-194	-235	-271
Maximum	12	7	-13	-42	-70	-112	-150	-188	-230	-267

Detailed results of all simulations and calculations can be found in the appendix.

Table 34: Best-case comparison of economic data in Jerba and Tunis, hospital case (TS2)

Demand	Location	Type	Fuel	Area [m²]	LHC [TD/MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
DHW + Circ + Space heating	Jerba	FPC	LPG	100	63,2	179.565	22,8	6,1	5,1
DHW + Circulation	Tunis	FPC	NG	100	70,0	14.102	7,9	16,4	11,2
DHW + Circ + Space heating	Tunis	FPC	NG	100	72,4	11.603	7,5	17,2	11,5

Figure 27:
Sensitivity analysis between collector area, storage tank size and system efficiency/solar fraction for flat plate collectors, hospital case (TS2)



The efficiency of the solar plant is similar to the hotel case. Here the curves start at a lower value because of the aforementioned missing conformity between demand and solar resources. The solar fraction is significantly lower. This is due to the additional demand for space heating, which obviously cannot be delivered with a reasonable efficiency. To increase the solar fraction the collector area would need to be much higher. The efficiency would then fall below 20%, with no chance of economic viability.

Case I, hospital with DHW and space heating versus natural gas

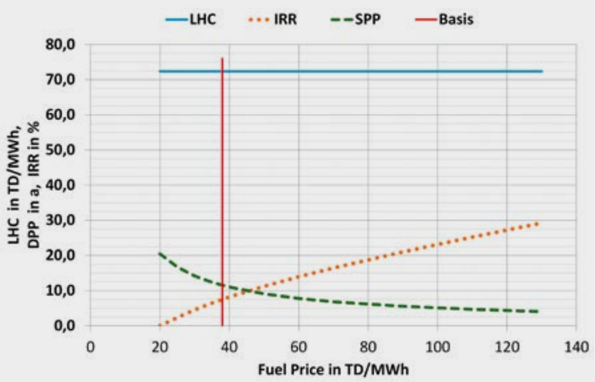
The results for Case I are presented in the following best-cases table. The static payback period of over 11 years does not fulfill the five-year criteria. However, in terms of financial mathematics, the dynamic payback period is below the lifespan and the internal rate of return is 7.5% over 20 years. This is 3.2% better than the inflation rate of 4.3%. The levelized heat costs of 72 TD/MWh are better than the levelized heat costs of natural gas.

Table 35: Economic evaluation of best economic cases depending on system size, hospital case (TS2)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/ m²]	LHC [TD /MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
100	0	1175	72,4	11.603	7,5	17,2	11,5
200	0	1024	78,3	6.812	6,5	19,0	12,3
300	0	903	85,7	-13.144	5,4	21,5	13,4
400	4	843	92,5	-41.695	4,4	24,0	14,3
500	8	797	97,3	-70.368	3,8	25,8	15,0
600	8	711	105,0	-111.807	2,9	29,1	16,1
700	12	669	110,4	-150.455	2,2	31,5	16,8
800	12	614	116,1	-188.364	1,6	34,3	17,6
900	12	561	122,5	-229.915	1,0	37,8	18,6
1000	12	520	127,8	-266.827	0,4	41,0	19,3

In conclusion, the economic feasibility of competing with natural gas is a bit worse than in the hotel case (Case III, 6.1.1.2.), although the sensitivities provide similar results. An improvement of the economic viability would require more expensive fuels than natural gas. For further sensitivities, see appendix.

Figure 28:
Sensitivity analysis of absolute fuel price effects on LHC, IRR, SPP, Tunis area with flat plate collectors, hospital case (TS2)



Case II, hospital case, DHW versus natural gas

To prove the impact of space heating, a system without solar supported space heating was simulated. The efficiency does not change (100 m²: 57%) and the solar fraction of domestic hot water only is 16% instead of 8%. This shows that additional space heating does not improve efficiency. For the system with domestic hot water only, there is no need to install an extra solar buffer tank for space heating. This lowers the investment costs and leads to slightly better economic viability: the static payback period is 11.2 instead of 11.5 years.

Case III hospital case, DHW and space heating versus LPG

The plant was simulated in Jerba to investigate the impact of a higher irradiation as well as to investigate the replacement of more expensive LPG. The result is similar to the hotel case (Case I, 6.1.1.2), a static payback period of 5.1 years.

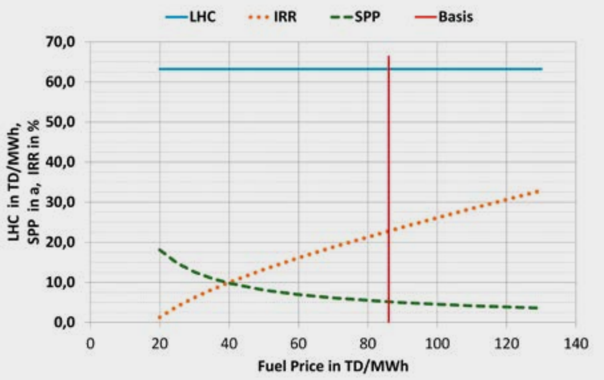
The sensitivity chart clearly shows that this is due to the significantly higher price of fossil fuel replacement (LPG). Considering a fuel price of natural gas (38 TD/MWh),

Table 36: Economic evaluation of one economic case depending on system size and storage volume, hospital case (TS 2)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/ m²]	LHC [TD /MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
100	0	1130	70,0	14.102	7,9	16,4	11,2

one can see that the SPP would jump to 10 years (see chart below). Better irradiation conditions only reduce the SPP by one year when compared to the Tunis case (Case I). This shows once again that the main obstacle for economic feasibility is the low price of natural gas.

Figure 29:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Jerba area with flat plate collectors (FPC), hospital case (TS2)



The sensitivity analysis also allows an evaluation of how economic boundary conditions would have to change in order to profitably run solar thermal systems that replace NG in the hospital sector. However, in order to avoid repetition in this study, the reader is invited to conduct his own interpretation of the sensitivity charts for TS2 (see also appendix). Please refer to 6.1.1.2 (TS 1, hotel case) as reference.

For this last case it might have been useful to analyze the cooling needs with solar thermal assisted cooling. Nevertheless, solar cooling was excluded from the study due to up-front cost considerations, which are very high for this technology. These conflict in particular with the very short payback times expected by investors.

6.1.3. TS 3 – Water heating of an indoor pool

6.1.3.1. Description of the object

In this case study a public indoor pool has been defined as one with 375 m² of surface situated in the more populous areas of Tunisia, e.g. Tunis and the tourist destination Jerba. The conventional heating system to be replaced is a gas or oil boiler or a LPG boiler for Jerba. The solar system is used only for heating pool water, not for space heating. At the same time, it could also be used for heating water for showers. As the temperature of pool water is lower in this case, the aim is to maximise the solar efficiency due to the lower temperature level needed. The pool water has to be heated throughout the year. The pool is described in the following tables:

Table 37: Basic data indoor, pool case, TS 3

Basic data	
Heating systems	Natural gas
Efficiency	88% (estimation - no data available)
Thermal capacity installed (kW)	320
Number of boilers	1
Age of boiler	More than 15 years
Sector	Public health sector
Subsector	Public indoor pool
Climate zone (coast, desert)	La Marsa Tunisia/coast Z1

Table 38: Basic assumptions and heat demand, indoor pool case (TS3)

Indoor Pool	
Pool surface	375 m²
Average depth of water	0,7-1,8 m
Pool covering used	No
Desired temperature of water	27 °C
Maximum pool temperature	29 °C
Indoor temperature	26 °C
Indoor humidity	65%
Operation period	1 Jan. - 31 Dec.
Daily time of usage	7:00-20:00

6.1.3.2. Results for TS3

Indoor pools are widely used in the area of Tunis as well as on the island of Jerba. Common fuels are natural gas and LPG on the island. The demand in this simulation is only for pool heating. The pool is filled once a year. The rest of the year heat demand results predominantly from evaporation losses. Note that the low indoor humidity, and the fact that the indoor temperature is less than the desired pool temperature. The results of the economic simulations are compiled in the following table.

For pool applications, solar plants do not need any solar buffer, as the pool itself acts as a thermal buffer.

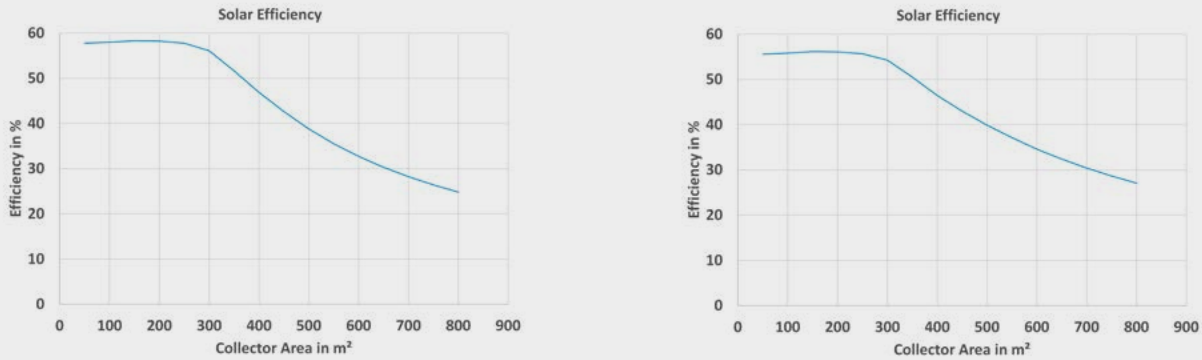
Table 39: Comparison of economic data in Jerba and Tunis, indoor pool (TS3)

Demand	Location	Type	Fuel	Area [m²]	LHC [TD/ MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
Indoor pool	Jerba	FPC	LPG	200	61,9	337.285	23,4	5,9	5,0
Indoor pool	Tunis	FPC	NG	150	71,1	18.660	7,7	16,8	11,3

Although the temperature level of pools is low (below 30°C), the efficiency of the solar thermal system is not higher than 60%. The reason can be found in the relatively high return temperature of 25°C. In comparison, DHW systems have return temperatures below 20°C. Domestic hot water, for example, has colder inlet temperatures but of course a much higher heat demand level to heat it up to appropriate temperatures.

This leads to a high level of solar efficiency. The higher irradiation and especially the higher ambient temperatures on Jerba allow for a slightly higher efficiency there. In both cases the efficiency remains stable, up to a collector area of 250 m².

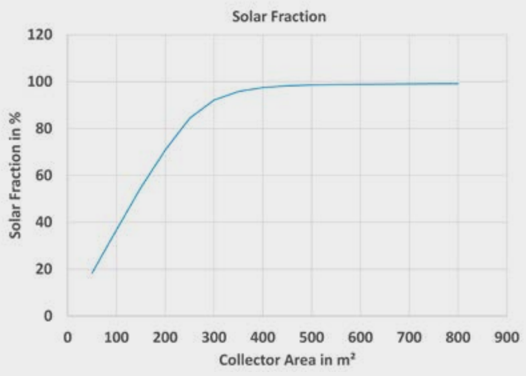
Figure 30:
Sensitivity analysis between collector area and system efficiency for flat plate collectors, indoor pool (TS3)



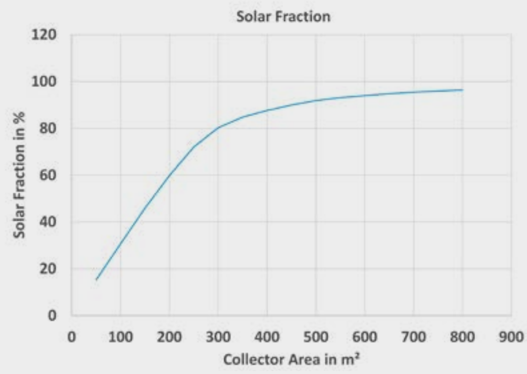
Jerba **Tunis area**

The higher efficiency yields to a higher solar fraction. On Jerba a solar fraction of nearly 100% is reached with a collector area as large as the pool area (375 m²).

Figure 31:
Sensitivity analysis between collector area and solar fraction for flat plate collectors, indoor pool (TS3)



Jerba



Tunis area

Table 40: Economic evaluation of best economic cases depending on system size in Tunis area , indoor pool (TS3)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/ m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
50	0	1111	71,3	6.170	7,7	16,8	11,3
100	0	1111	71,2	12.381	7,7	16,8	11,3
150	0	1100	71,1	18.660	7,7	16,8	11,3
200	0	1064	72,7	20.383	7,5	17,2	11,5
250	0	1021	74,8	18.476	7,1	17,9	11,8
300	0	944	79,9	4.581	6,2	19,5	12,5
400	0	777	94,7	-45.749	4,1	24,8	14,6
500	0	655,6	109,3	-101298,0	2,4	31,0	16,7
600	0	561	124,4	-160.120	0,8	38,8	18,8
700	0	490	138,6	-217.078	0,0	48,0	20,9
800	0	434	152,3	-271.971	0,0	59,4	22,9

The best economic case is in Tunis 150 m² with a solar fraction of 45%. Nevertheless, 200 m² yields a solar fraction of 60% and is only slightly less profitable. Since the pool is used all year, additional heating from conventional sources is needed.

The economic viability of solar thermal versus natural gas is worse than versus LPG. Therefore, on the island of Jerba, a solar fraction of 100% can be reached with a static payback period of six years.

Table 41: Economic evaluation of best economic cases depending on system size on Jerba , indoor pool (TS3)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
50	0	1320	60,0	90.436	24,0	5,7	4,9
100	0	1317	60,1	180.311	24,0	5,8	4,9
150	0	1299	60,2	266.452	23,9	5,8	4,9
200	0	1249	61,9	337.285	23,4	5,9	5,0
250	0	1194	63,9	396.159	22,7	6,1	5,1
300	0	1090	69,2	414.848	21,1	6,6	5,5
400	0	871	84,4	383.362	17,4	8,0	6,5
500	0	706,7	101,4	322628,0	14,4	9,7	7,6
600	0	591	118,1	258.216	12,1	11,5	8,6
700	0	508	133,8	197.087	10,3	13,3	9,6
800	0	445	148,6	139.318	8,8	15,1	10,5

Exemplary discussion of the impact of climate data: Tunis versus Jerba

The differences in the fuel price sensitivities depicted are based only on different climate conditions:

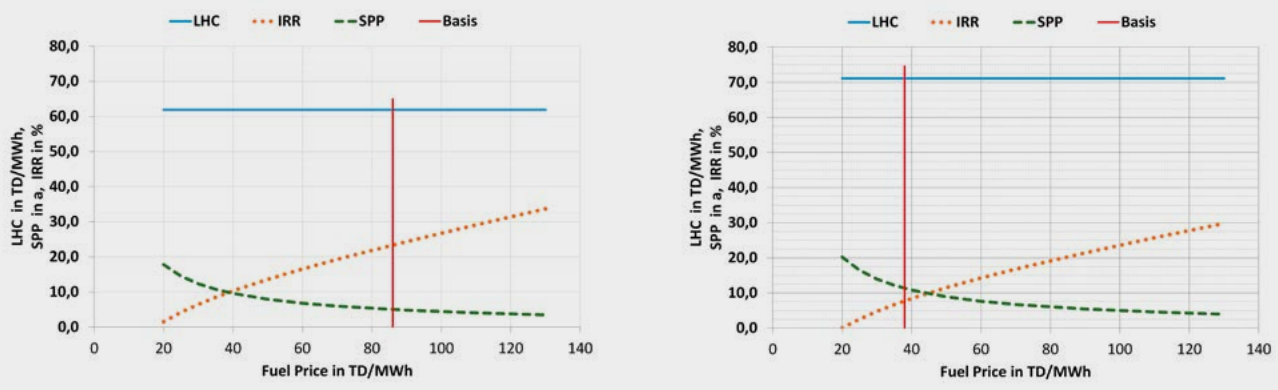
- The levelized heat costs are 71 (Tunis) respectively 62 TD/MWh (Jerba).
- The fuel price to generate 10% IRR as well as for 10 years payback period is TD 45/MWh in Tunis and TD 39/MWh in Jerba.

The discussion of the sensitivities of the amount of subsidy grant is the same as in the case studies for hotels (6.1.2) and hospitals (6.1.3). See detailed charts in the appendix.

Though it might be interesting to investigate the effect of including showers and other DHW installations as well, the focus was on a low temperature application of swimming pools. It can be assumed that the showers could be provided with solar hot water as well. The case would be very similar to the hotel case.

If only pool water is provided, it could also be cost efficient option to only use unglazed swimming pool absorbers. This option has not been analyzed in the course of the study, since this technology receives no ANME support.

Figure 32:
Sensitivity analysis for the fuel price, indoor pool (TS3)



Jerba

Tunis area

6.1.4. TS4 – Hot water for a collective residence

6.1.4.1. Description of the object

For this case study, a typical residence for military purposes has been defined as one for 80 residents. The conventional heating system is usually natural gas, LPG or oil boiler, depending on the site and access to fuel. In rare cases it could also operate with an electrical heating element.

Table 42: Basic data, military residence case, TS 4

Basic data	
Heating system (possible natural gas, LPG, light heating oil)	Natural gas
Efficiency	88% (estimation - no data available)
Thermal capacity installed (kW)	80
Number of boilers	1
Age of boiler	More than 15 years
Sector	Public sector
Subsector	Residences
Climate zone (coast, desert)	La Marsa Tunisia/coast Z1

The annual hot water demand is 1,800 m³ at 60°C. The hot water is needed in the morning and noon, but mostly in the evening for sanitary, washing and cooking purposes. The monthly profile is as follows:

Due to higher outside temperatures during the summer, less hot water is needed, cold water from the tap is warmer and losses are lower. This effect does not show in the hotel case, since the hot water consumption remains high due to the consistently high number of tourists.

The residence for this case study could also be a residence for students (e.g. boarding school or university), although long holidays and the correspondingly long absence of residents lead to less interesting hot water demand profiles during the year. This translates into lower solar efficiencies (and significantly lower profitability), since the solar plant would not be operational for certain periods of time.

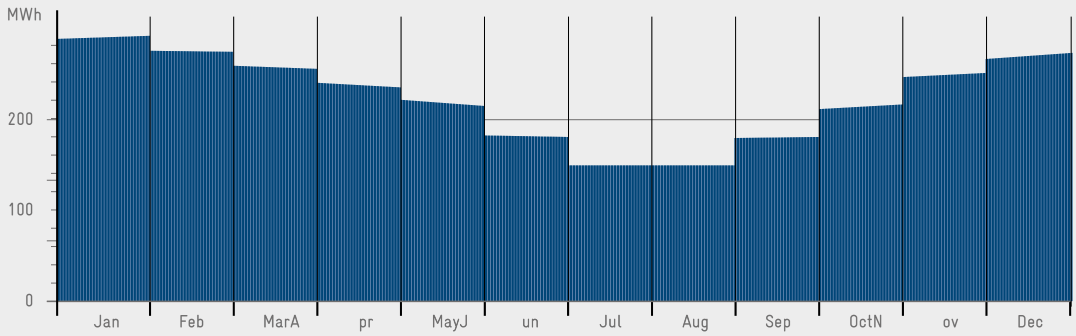
6.1.4.2. Results for TS4

The demand for domestic hot water with 1,800 m³ a year (60°C) is quite low (hospital case: DHW 11,000 m³, hotel case: DHW 22,000 m³). As a location for the case study, the area of Tunis was chosen. An already existing stand-by tank with a capacity of 500 litres is presupposed. An additional solar buffer up to 4 m³ is under investigation for the tank optimization.

Table 43: DHW demand profile in m³ and percent, military residence case (TS4)

Profile in % of the annual hot water demand												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
191.952	163.744	170.624	154.800	149.296	123.840	106.640	106.640	123.840	149.296	165.120	181.288	1.787.080
10,7%	9,2%	9,5%	8,7%	8,4%	6,9%	6,0%	6,0%	6,9%	8,4%	9,2%	10,1%	100,0%

Figure 33:
DHW demand profile, military residence case (TS4)



Simulation period 01.01 - 31.12
E Preset - DHW 80.839 kWh

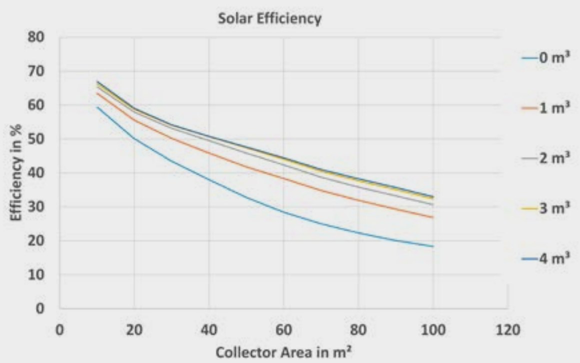
Table 44: Comparison of economic data in Jerba and Tunis, residential case (TS4)

Location	Type	Fuel	Area [m²]	LHC [TD/MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
Jerba	FPC	LPG	10	60,1	18.256	24,2	5,7	4,9
Tunis	FPC	NG	10	67,4	1.822	8,5	15,6	10,8

An economic sensitivity analysis has been carried out for the Tunis area with a comparison to natural gas, and additionally in Jerba with a comparison to LPG.

Although the demand distribution over the year is similar to the hospital case, there is a difference in demand structure: For the residential case, no circulation loop is provided, showers are used only mornings and evenings. The comfort level is low. This lowers total demand and increases solar efficiency because the temperature of the return circulation (>50°C) is high and contributes to higher solar loop temperatures. This means a smaller solar plant is needed in relation to the hospital case.

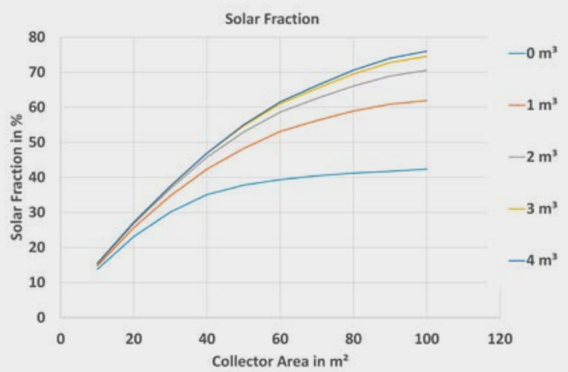
Figure 34:
Sensitivity analysis between collector and storage tank size and solar efficiency for flat plate collectors, residential case (TS4)



The impact of the solar buffer volume on the solar fraction is higher than in the hospital case. This is because the average daily consumption of 5 m³ is distributed in a morning and an evening peak.

The best-case analysis results in the area of Tunis for the smallest plant (collector area: 10 m²): a static payback period of 10.8 years (solar fraction ~ 15%). Although

Figure 35:
Sensitivity analysis between collector and storage tank size and solar fraction for flat plate collectors, residential case (TS4)



it is higher than the desired five years, the internal rate of return of 8.5% is 4.2% higher than the assumed inflation rate of 4.3%, thus making it economically viable (i.e. no financial losses are generated).

The analysis confirms that for large plants with a higher solar fraction, an extra tank volume is worth considering.

The sensitivity analysis at the Tunis location again confirms that a higher fuel price would significantly increase profitability. The impact of a energy price increase rate increases linearly with the internal rate of return, but the effect on the static payback period is less than linear, showing a slight decline.

The comparison to the Jerba location and the calculation against LPG provide totally different results. The static payback period for the same plant is 4.9 years.

The sensitivity analysis for the fuel price confirms that compared to natural gas (38 TD/MWh), the SPP would increase to almost 10 years.

Table 45: Economic evaluation of best economic cases depending on system size and storage volume, residential case (TS4)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
10	0	1188	67,4	1.822	8,5	15,6	10,8
20	1	1108	85,7	-1.063	5,4	21,5	13,3
30	2	1059	94,3	-4.546	4,2	24,6	14,5
40	2	987	96,2	-6.485	3,9	25,4	14,8
50	2	913	100,8	-9.801	3,4	27,2	15,5
60	3	877	108,2	-15.641	2,5	30,4	16,5
70	3	806	115,2	-21.108	1,8	33,7	17,5
80	3	749	121,8	-26.780	1,1	37,2	18,4
100	3	643	138,4	-40.556	0,0	47,5	20,7

Figure 36:
Sensitivity analysis for the subsidy rate, residential case (TS4)

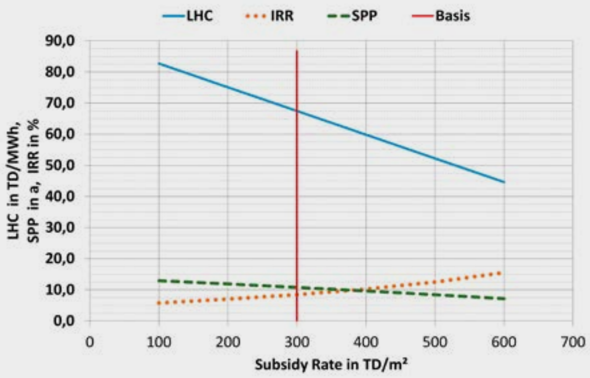
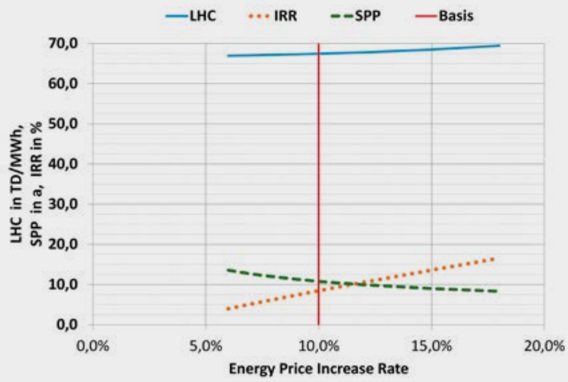


Figure 37:
Sensitivity analysis for the fuel price, residential case (TS4)

Figure 38:
Sensitivity analysis for the energy price increase rate, residential case (TS4)



6.1.5. Summary on tertiary sector

Earlier paragraphs (6.1.1-6.1.4) described the profitability of tertiary solar thermal plants on a case-by-case basis. The following table sums up the best economic results of the presented case studies and provides a first orientation on general profitability in the tertiary market. The profitability ranking clearly shows that the main determining factor for an economic solar plant is the fuel price. Economics are thereby highly dependent on whether the final consumer (investor) will replace natural gas or LPG as a fuel source (price difference of about 50%). This, however, depends on whether the investor is connected to the natural gas grid or not. Only in Jerba (where there is no natural gas grid yet) can static payback periods of around five years be reached.

6.1.5.1. Location influence factors for the investment decision

Jerba represents a more appropriate climate for the use of solar thermal and competition with LPG. As explicitly described in the case studies, the crucial advantage of Jerba is the competition with LPG. But the higher irradiation and the higher ambient temperatures in Jerba in comparison with Tunis also improve the static payback periods by close to two years. The lower temperature level demanded and even more importantly, the lower temperature difference to the ambience favour flat plate collectors over vacuum tube collectors (see 6.1.1.2, Case II).

6.1.5.2. Influence of economic assumptions for investment decision

Based on economic considerations as well, flat plate collectors are the better choice. In addition, from an economic point of view, it is more advantageous to invest in small systems with low solar fractions for the entire heating system.

The profitability of solar thermal systems is largely determined by investment costs per m² (subsidy scheme) and by the cost of the respective fossil fuels to replace (fuel price savings). Solar thermal systems tend to be profitable on Jerba when LPG is replaced (see table 42). However, replacing the less expensive NG in Tunis leads to significantly lower monetary gains per energy savings, but does not correspond to economic expectations of the investors. Even the best tertiary case system only provides relatively less profitable SPPs of 10 years.

In Tunisia the majority of investors demand static payback periods of five years or less. Considering the simple equation that economic viability is only given when the SPP is lower than five years, either one of the following events would have to be true (see sensitivity analysis 6.1.1-6.1.4):

- subsidy rates of about 700 TD/m² (equals an increase of more than 100%)
- NG price of around 80 TD/MWh[53] (currently only 38 TD/MWh) while maintaining the energy price increase scenario as defined in 5.2.1

The rate of the energy price increase does not play such an important role in lowering the SPP, since the increase starts from very low levels. Its effect over the first five years of the solar plant's operation thus remains limited.

[53] *Represents an adjustment to similar levels as the current the LPG price.*

Table 46: Profitability ranking of best-cases of tertiary sector

ID	Case	Demand	Location	Type	Fuel	Area [m²]	LHC [TD/MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
TS 1	Hotel	DHW + circulation	Jerba	FPC	LPG	100	54,2	209.973	26,3	5,2	4,5
TS 4	Residence	DHW	Jerba	FPC	LPG	10	60,1	18.256	24,2	5,7	4,9
TS 3	Pool	Indoor pool	Jerba	FPC	LPG	200	61,9	337.285	23,4	5,9	5,0
TS 2	Hospital	DHW + circ + space heating	Jerba	FPC	LPG	100	63,2	179.565	22,8	6,1	5,1
TS 1	Hotel	DHW + circulation	Jerba	CPC	LPG	400	80,1	611.876	18,1	7,7	6,3
TS 1	Hotel	DHW + circulation	Tunis	FPC	NG	100	61,4	28.409	9,7	14,0	9,9
TS 4	Residence	DHW	Tunis	FPC	NG	10	67,4	1.822	8,5	15,6	10,8
TS 2	Hospital	DHW + circulation	Tunis	FPC	NG	100	70,0	14.102	7,9	16,4	11,2
TS 3	Pool	Indoor pool	Tunis	FPC	NG	150	71,1	18.660	7,7	16,8	11,3
TS 2	Hospital	DHW + circ + space heating	Tunis	FPC	NG	100	72,4	11.603	7,5	17,2	11,5

It must noted that demanding SPPs of equal or lower to five years is a very strong economic requirement for renewable energy systems in general (high initial investment costs, but steady, regularly divided returns over 20 years) and for solar thermal in particular. Often, a simple evaluation of the payback period does not represent a comprehensive economic evaluation, since the majority of solar revenue does not enter the equation. That is why it is also interesting to look at other economic indicators (e.g. IRR, NPV or comparing LHCs).

Already today, all calculated IRRs for the best tertiary cases (table 42) are positive and stand above inflation levels. This means that the investment does not lead to a financial loss (also by considering the time value of money). However, the calculated NPVs and IRRs have to be set against the context of other investment opportunities (such as expansion/building of additional hotel rooms or other energy efficiency measures) and thus compared to their economic performance.

These types of evaluation will depend on the investor's perspective and his decision to invest in either long-term or short-term oriented investments.

If a longer SPP or DPP would be accepted, solar thermal systems might become more economically viable all over Tunisia in the tertiary sector (including those regions which are already connected to the natural gas grid). This development, however, is based on the assumption (basic requirements for profitability) that

- … the current solar thermal subsidy scheme of 55% investment grant (150 TD/m² ANME; 150 TD/m² UNEP) will continue in the future.

- … energy prices keep rising (increase rate of 10%/yr (first five years) and then 5%/yr (for the following 15 years).

Concerning a), it is realistic to assume that ANME's investment grant of 150 TD/m² will remain active for the upcoming years. However, it must be noted that the additional 150 TD/m² (extending to 300 TD/m²) currently originate from international funds which might not remain in place forever.

Concerning b), recent drops in oil and gas prices might slow down the political will for subsidy reforms, thus leading to less ambitious energy price scenarios.

6.1.5.3. Influence of application for investment decision

Space heating was simulated for the hospital case only. Nevertheless, it could be shown that the heating period is too short to pay back the additional investment needed. For hotels, space heating is usually provided via their air conditioning systems and thus does not apply for these cases.

As elsewhere, the circulation loop lowers the efficiency of the solar plant. If it is dispensable in terms of comfort, it should be omitted. This depends on the requirements of each site and should be verified.

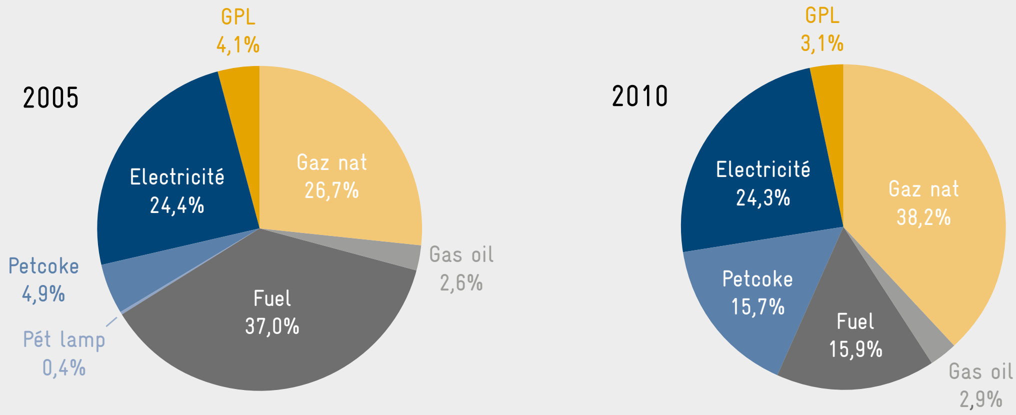
One significant advantage in the tourism sector is that the demand is higher in summertime. This improves the conformity of heat demand and solar irradiation and means that the required collector area for winter demand does not produce a solar surplus in summer and that an exclusive supply is economically justifiable. This is especially interesting for hotels, where the use of fossil fuel boilers (auxiliary systems) can be completely avoided with a CPC system providing 100% of hot water supply.

6.2. Industry cases

The Tunisian industry sectors with the highest potential for solar heat integration are the food, chemical, textile and brick production industries, as they mainly require low or medium temperature levels (50°C-200°C) This covers processes such as washing, cleaning and drying, as well as the supply of steam for the heat distribution systems of companies. The brick industry forms an exception, since only one of the production steps (drying of bricks) is technically exploitable for solar thermal systems. Industry processes with temperature requirements above 250°C are not considered, since the efficiency of solar thermal systems decreases significantly above this temperature and the technical requirements become demanding.

The following chart shows the distribution of thermal energy consumption in the industry. The industry sectors with low and medium temperature demand that are

Figure 39:
Energetic distribution in the Tunisian industrial sector



Source ANME 2013

relevant for solar thermal (food, textile, chemical, brick, various) represent around one third of the total thermal energy consumption of the Tunisian industry.

Around 70% of companies in the relevant sectors use natural gas as heating source; around 30% use fuel oil. Since fuel oil is more expensive and the natural gas network is gradually expanding, also in remote areas of the country, more and more companies are switching to natural gas and the share of NG as heating source is increasing.

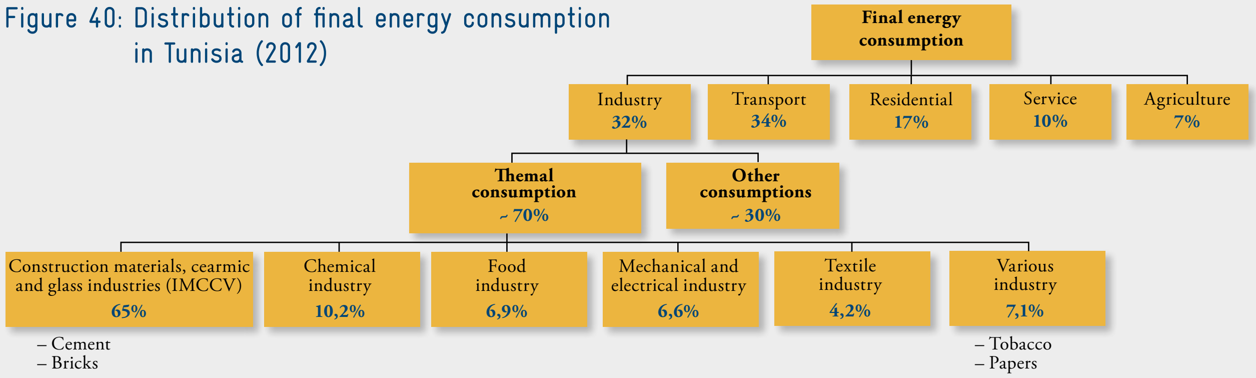
In the on-going GIZ project "DASTII", industry companies from the food, chemical, textile and brick sectors were investigated in detail for their technical potential and their willingness to make use of solar thermal energy. Factors like limited ground space, limited roof bearing capacity or shading through neighbouring buildings reduced the number of potential sites. Subsequently, pre-selection questionnaires were provided from around 15 suitable companies and detailed energy audits and feasibility studies were executed for the five most promising companies. These study results were taken into account for the definition of the representative cases, since they provided insight into and information on relevant industrial processes in Tunisia.

Table 47: Location of industrial zones in Tunisia

Governorates	Existing industrial zones	Planned industrial areas
Ariana	6	1
Béja	9	0
Ben Arous	22	1
Bizerte	8	
Gabès	3	
Gafsa	8	
Jendouba	4	5
Kairouan	7	5
Kasserine	6	
Kébili	4	0
Kef	2	2
Mahdia	5	0
Manouba	8	3
Médenine	3	2
Monastir	8	2
Nabeul	10	4
Sfax	16	0
Sidi Bouzid	1	1
Siliana	7	0
SOUSSE	8	1
Tataouine	11	1
Tozeur	8	0
Tunis	6	1
Zaghouan	9	
Total	179	29

Source: http://www.tunisieindustrie.nat.tn/fr/dr.asp, 15. Apr. 2015

Figure 40: Distribution of final energy consumption in Tunisia (2012)



Source ANME 2013

Table 48: Energy consumption share in the Tunisian industry

Energy	2010	
	toe	%
Electricity	532.151	24,6%
Natural gas	838.170	**38,8%**
Other	789.899	**36,6%**
Fuel oil	348.259	16,1%
Petroleum coke	344.100	15,9%
LPG	34.115	1,6%
Gas oil	62.958	2,9%
Pét lampant	467	0,0%
Total	2.160.220	100,0%

The following analysis focuses on four industry cases which cover all relevant scenarios according to the categories of collector technology (flat plate, vacuum tube, concentrating collector), integration method (supply level, process level, preheating), temperature level (55-165°C), location (north, south) and the heating source replaced (natural gas, fuel).

The definition of simulated cases is based on the input data of existing companies that is deemed to be representative for the sector.

The following four main cases were selected for detailed simulation and analysis:

Table 49: Case study selection for industrial sector

Sector	ID	Branch	Location	Technology simulated	Heating system	Solar supported demand
Industrial Sector	IS1	Food	Sousse	CPC LFC	Natural gas	Supply level Feed water preheating 75°C: 45 -105
Industrial Sector	IS2	Food	Tunis area	FPC CPC	Heavy fuel	Process level Hot water 55°C: 25-85
Industrial Sector	IS3	Textile	Tunis area	CPC LFC	Natural gas	Supply level Saturated steam 165°C
Industrial Sector	IS4	Bricks	Tunis area	CPC LFC	Natural gas	Supply level Hot air 70°C: 25 - 120°C

6.2.1. IS1 – Feed water preheating in food industry

For this case study a typical steam boiler system based on natural gas has been analyzed. Two gas boilers produce the yearly steam demand of 33,000 tons. The following table describes the system, which is based on data from a dairy industry case:

Table 50: Basic assumptions, dairy industry case (IS1)

Basic data	
Heating system	Natural gas
Boiler efficiency	90%
Thermal capacity installed / kWh	14.840
Number of boilers	2
Sector	Industry
Subsector	Food
Products	Milk
Climate zone	Sousse
Operation period	24 h/7 days a week/ 365 days per year
Total consumption gas Nm3	2.792.163

The average boiler efficiency over the year is assumed to be 80% instead of the maximum achievable efficiency of 90% due to partial load below full capacities and standby times. The boilers generate around 23,000 MWh of heat per year, which corresponds to 33,000 tons of steam. Nevertheless, with a capacity of 15 MW they could produce up to four times more heat than currently needed.

Table 51: Monthly energy demand profile, dairy industry case (IS1)

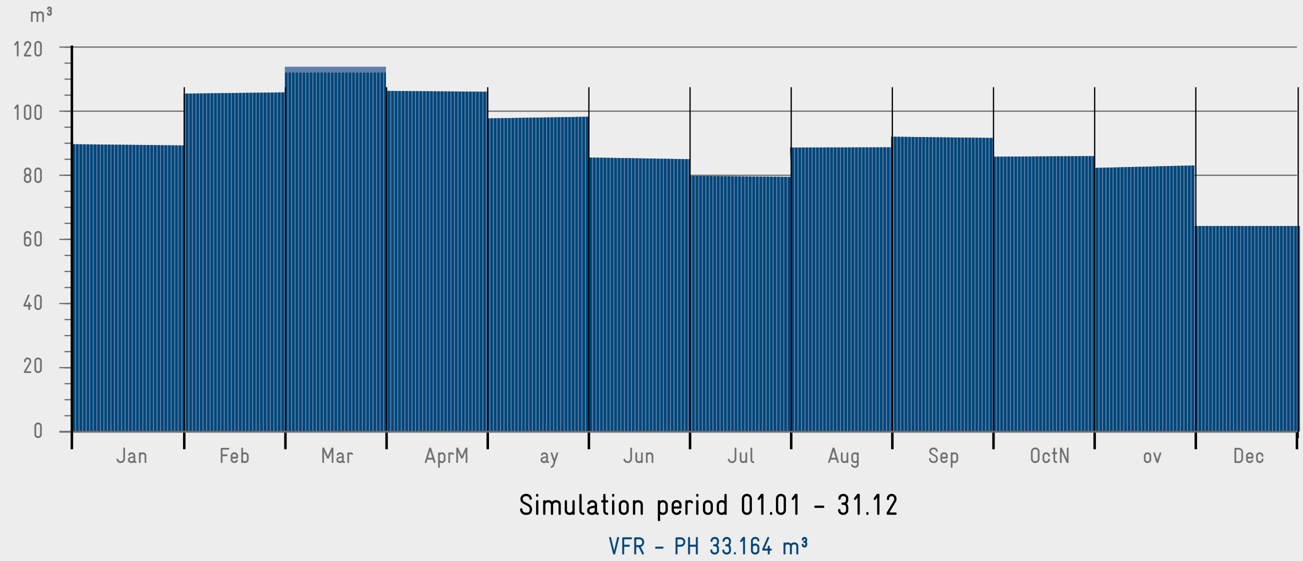
Profile in % of the annual gas demand												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total
228.664	270.426	290.457	270.426	252.344	218.406	204.209	224.987	234.094	219.439	212.857	165.854	2.792.163
8,2%	9,7%	10,4%	9,7%	9,0%	7,8%	7,3%	8,1%	8,4%	7,9%	7,6%	5,9%	100%

Table 52: Temperature level of different processes

	Temperature Level (°C)			
Medium	Supply temperature of process water	Condensate return temperature	Supply temperature to the process	Annual gas consumption Nm^3
Steam	25	50	190	2.792.163

The amount of feed water for the steam boilers remains quite constant over the year:

Figure 41: Annual steam consumption profile, industry case (IS1)



Hot water provided by the solar system and the boiler feed water can be easily stored. Therefore, it is not necessary to know the actual hourly steam demand. The assumption is that the daily and hourly profile is constant. The solar system can preheat the feed water from 45°C to a maximum of 105°C. The lower temperature results from mixing the return temperature outlet water and the cold water added to the steam system. The upper temperature is limited by the steam process, since de-aeration does not work above this temperature. The resulting annual preheating heat demand is 2.312 MWh.

6.2.1.1. Results for IS1

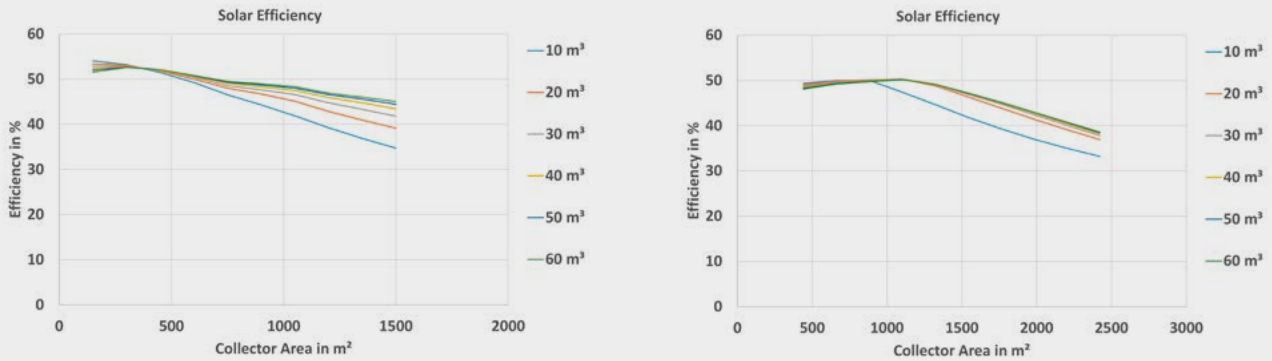
Three different scenarios were simulated for this case: vacuum tube collectors (CPC) and linear Fresnel collectors (LFC) at the Tunis location in and vacuum tube collectors (CPC) at the Sfax location. The fuel source is natural gas. The solar loop works with a solar buffer for which a tank optimization is analyzed (see chapter 5 for methodology). In the appendix, the results of all simulations and calculations are listed in detail.

For the Tunis location, the impact of the collector type is analyzed. At this temperature level (preheating from 45°C to 105°C), the efficiency and the solar fraction of the vacuum tubes and the linear Fresnel collectors are similar. The economic result is better for the CPC because LFC are significantly more expensive than CPC. However, in neither case is economic viability achieved. The net present values are negative and the internal rate of return is lower than the given interest on capital of 8%.

Table 53: Comparison of best-cases for the three selected scenarios for feed water preheating (IS1)

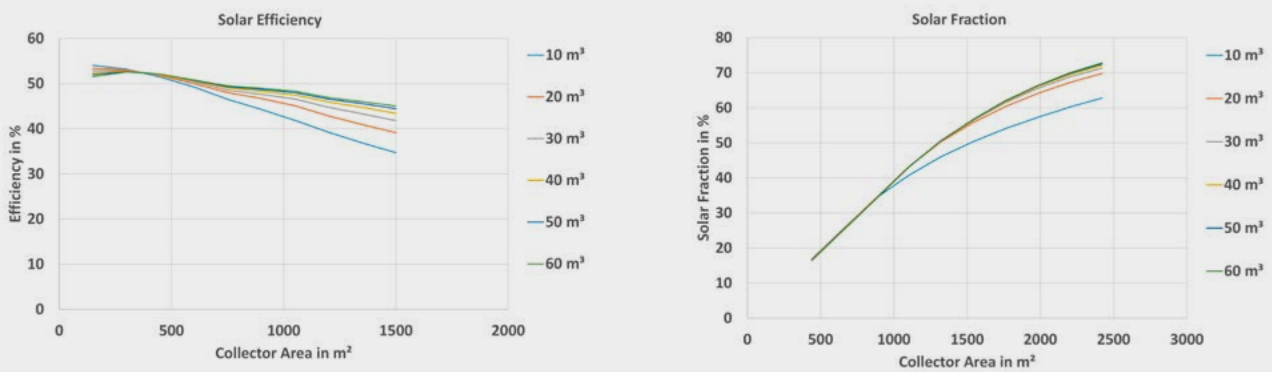
Location	Type	Fuel	Area [m2]	LHC [TD/MWh]	NFV [TD]	IRR [%]	DPP [y]	SPP [y]
Sfax	CPC	NG	1050	115,7	-297.500	4,4	33,8	14,3
Tunis	CPC	NG	1050	133,2	-411.941	2,8	47,9	16,1
Tunis	LFC	NG	1980	181,6	-1.339.295	< 0	> 100	24,1

Figure 42:
Solar efficiency for CPC and LFC, feed water preheating (IS1)



Linear Fresnel Collectors **Vacuum Tube Collectors**

Figure 43:
Solar fraction for CPC and LFC, feed water preheating (IS1)



Linear Fresnel Collectors **Vacuum Tube Collectors**

Table 54: Best-case analysis with LFC in Tunis, feed water pre-heating (IS1)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
440	10	888	284,0	-732.885	< 0	> 100	40,7
660	10	901	263,3	-998.323	< 0	> 100	36,8
880	10	903	242,8	-1.179.134	< 0	> 100	33,3
1100	10	856	235,5	-1.333.420	< 0	> 100	32,2
1320	20	881	212,9	-1.396.184	< 0	> 100	28,5
1540	20	838	203,1	-1.429.455	< 0	> 100	27,1
1760	20	793	192,9	-1.411.025	< 0	> 100	25,6
1980	20	748	181,6	-1.339.295	< 0	> 100	24,1
2200	20	706	188,8	-1.511.197	< 0	> 100	25,2
2420	20	667	198,6	-1.718.292	< 0	> 100	26,8

Table 55: Best-case analysis with vacuum tube collectors (CPC) in Tunis, feed water preheating (IS1)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
150	10	1050	162,2	-113.388	0,7	100,0	19,0
300	10	1037	146,8	-178.603	1,7	66,7	17,5
450	10	1005	141,3	-235.933	2,2	57,5	16,9
600	10	961	139,2	-289.254	2,3	54,7	16,7
750	10	908	139,1	-341.194	2,3	54,8	16,7
900	10	867	137,5	-378.834	2,4	52,8	16,6
1050	20	882	133,2	-411.941	2,8	47,9	16,1
1200	30	872	135,7	-490.330	2,6	50,6	16,4
1350	30	844	137,6	-555.017	2,4	53,1	16,6
1500	40	846	137,7	-619.682	2,4	53,2	16,6

Sensitivity analysis for the best-case in Tunis

As mentioned in chapter 5, the profitability of solar thermal systems is mainly determined by the investment costs per m² (subsidy scheme) and by the cost of the respective fossil fuel source to be replaced (fuel price savings).

The profitability expectations among industry investors are particularly high, since they follow a short-term investment perspective and can often choose among many profitable investment alternatives in order to increase profits (production extension, equipment upgrades, energy efficiency, etc.).

Experience shows that decision-makers in the Tunisian industry expect their investments to be paid back in a period of maximum five years.

A look at the sensitivities of IS1 best-case in Tunis reveals that the following would be required in order to reach a SPP of five years:

- **grant subsidies of 950 TD/m² (equal to six times the current incentive or 90% of the global investment costs), or**
- **energy price increase rate of over 60%/ per year (current assumption: 10% for the first six years, afterwards 5%), or**
- **NG price level of 140 TD/MWh (currently 38 TD/MWh)**

Figure 44:
Sensitivity analysis for the subsidy rate, feed water preheating (IS1)

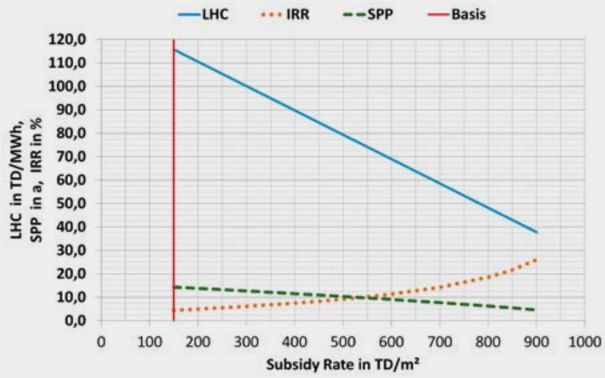


Figure 45:
Sensitivity analysis for fuel price, feed water preheating (IS1)

Figure 46:
Sensitivity analysis for energy price increase rate, feed water preheating (IS1)

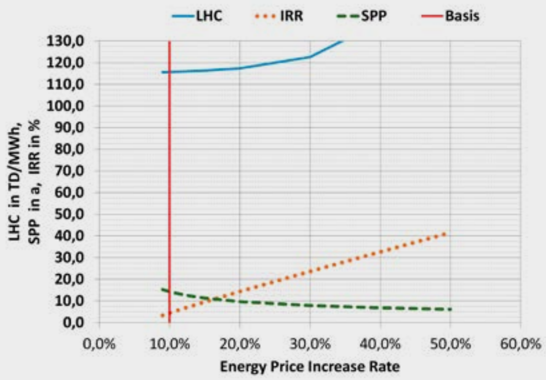
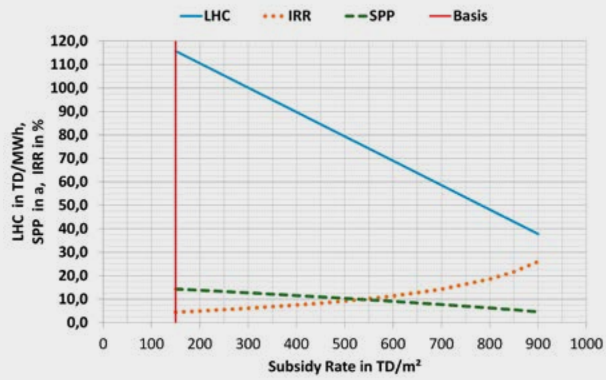


Figure 47:
Sensitivity analysis for the subsidy rate, Sfax, feed water preheating (IS1)



In general it can also be concluded that a) and c) are the main influencing factors and by their nature absolute preconditions for economic viability (low SPPs). The energy price increase rate also represents an important factor, but since the increase starts from very low levels, its effect over the first five years of operation of the solar plant is limited.

The situation at a location with higher irradiation (e.g. Sfax) yields slightly better, but also insufficient results. The collector area with the best results is between 900 and 1350 m² with a static payback period of about 14 years.

Figure 48:
Sensitivity analysis for the fuel price, Sfax, feed water preheating (IS1)

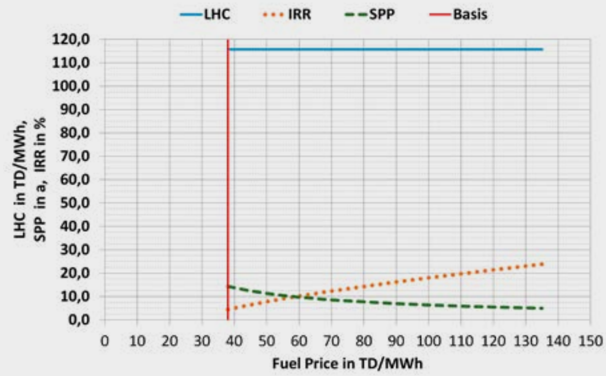


Table 56: Best-case analysis with vacuum tube collectors (CPC) in Sfax, feed water preheating (IS1)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
150	10	1212	140,5	-93.559	2,2	55,9	16,8
300	10	1194	127,5	-140.018	3,3	42,1	15,5
450	10	1155	122,9	-180.628	3,7	38,6	15,0
600	10	1106	120,9	-217.920	3,9	37,2	14,8
750	10	1046	120,7	-256.396	3,9	37,1	14,8
900	20	1050	117,3	-278.170	4,3	34,8	14,4
1050	20	1015	115,7	-297.500	4,4	33,8	14,3
1200	30	1006	117,7	-359.380	4,2	35,1	14,5
1350	40	1005	118,2	-410.821	4,2	35,4	14,5
1500	40	976	119,5	-461.160	4,0	36,3	14,7

Excursus: Results for proposed new subsidy mechanism (ANME)

As described in the excursus in chapter 5, this mechanism changes the boundary conditions for financing and subsidies. There is a subsidy of TD 150/m² collector area on the investment. In addition, there are soft loans at 2% for 25% of the investment and a period of 15 years including five years grace period and at 5% for 45% of the investment for 10 years.

Table 57: Assumptions FTE subsidy model

Assumptions	Value	Unit
Price before subsidy	70	TD/MWh
Price after subsidy	38	TD/MWh
Increase rate factor years 1-6	110,0%	
Increase years 7-20	105,0%	
Increase rate factor for gas price before subsidy	100,5%	
Degradation factor	99,5%	
Discount factor	107,0%	
Solar yield (TS 1,1-1,4 IS 0,8-1)	1	MWh/m² coll.area
Boiler efficiency	80,0%	

The solar savings result in TD 140/MWhm² collector area for natural gas, if the solar system was installed in year one. In the calculation, they increase the grant. The values for Sfax vary between approximately 0.8 und 1.2 MWh/m². If multiplied by 25% this would result in additional support of TD 35/m² collector area.

The FTE credit line at 2% interest rate provides additional subsidy of 41.2% for the amount supported or 10.3% of the total investment.

The remaining credit subsidises the loan with 13.1% or 5.9% of the total investment.

The total support of the system varies between 28% and 33%, depending on the size and thus on efficiencies and overall costs.

- For the calculations of the IRR, annual savings have been discounted over 20 years with the variable discount factor until the residual sum correlates to the remaining investment sum.
- The calculation of the Dynamic Payback Period (DPP)[54] has been discounted with the interest on capital rate of 8% and totalled to correlate with the remaining investment sum.
- For the calculation of the SPP, annual savings have been totalled up until the sum of the NPV corresponds to the residual investment sum. It can therefore not be calculated via generic formulas and is given for the best-case only.

Result

If calculated under the assumptions above, the best IRR results in 7% and the best DPP is 22.8 years for a 1050 m² system.

[54] *In this case the DPP has to be taken as reference, since the ANME subsidy scheme involves a highly dynamic form of support.*

Table 58: Subsidy mechanism FTE, economic overview for CPC, Sfax area, feed water preheating (IS1)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/ m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]
150	10	1212	115,2	-49.838	4,4	34,1
300	10	1194	104,0	-60.106	5,6	27,7
450	10	1155	100,0	-67.578	6,1	25,7
600	10	1106	98,2	-74.888	6,3	24,9
750	10	1046	97,9	-86.726	6,4	24,8
900	20	1050	95,0	-78.271	6,8	23,5
1050	30	1047	93,3	-73.589	7,0	22,8
1200	30	1006	95,2	-102.387	6,7	23,6
1350	40	1005	95,7	-120.884	6,7	23,8
1500	50	999	96,4	-144.365	6,6	24,1

For this best-case, the investment assumptions are shown in the following table.

Table 59: Investment for best-case FTE subsidy scheme, best-case CPC

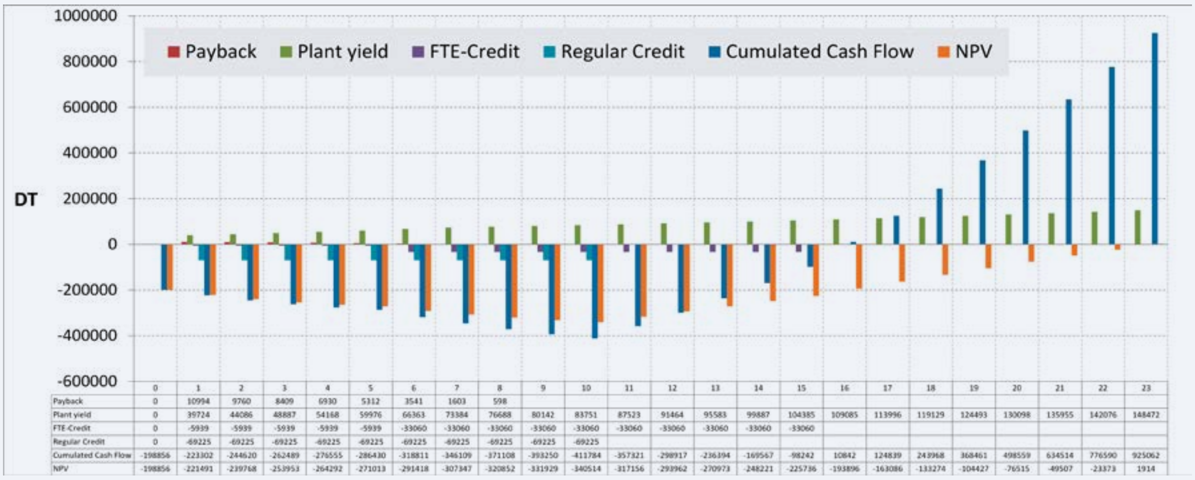
Item	TD	Planed	Contribution to investment in %
Total cost	1187855	100%	
Subsidy grant (150 TD/ m²):	157500		13,3%
Equity	198856	30%	
Soft loan FTE (2% interest rate / 5 years grace period	296964	25%	10,3%
Soft loan (5% interest rate)	534535	45%	5,9%
Additional income by saved subsidies			
(140 TD / m²) * 0,25	3675		3,1%
Total subsidy			32,6%
Changed SPP due to FTE mechanism		16,7 years vs. 14,3 years (without FTE)	
Improved DPP due to FTE mechanism		23,8 years vs. 33,8 years (without FTE)	

The investment grant reduces the equity accordingly and represents 13.3% of the investment.

The following cash flow modelling allows reaching the SPP in year 16, which is later than without the FTE support.[55] The effects on DPP are striking, with an improvement of 10 years. The total subsidy increases to 32.6% instead of 13.3% in the equity only case.

[55] *The calculation of the SPP is case sensitive and therefore cannot be provided in the table for all cases.*

Figure 49:
Cash flow simulation for best-case scenario FTE ANME subsidy scheme for IS1



	0	1	2	3	4	5	6	7	8	9	10	11
Payback	0	10994	9760	8409	6930	5312	3541	1603	598			
Plant yield	0	39724	44086	48887	54168	59976	66363	73384	76688	80142	83751	87523
FTE-Credit	0	-5939	-5939	-5939	-5939	-5939	-33060	-33060	-33060	-33060	-33060	-33060
Regular Credit	0	-69225	-69225	-69225	-69225	-69225	-69225	-69225	-69225	-69225	-69225	
Cumulated Cash Flow	-198856	-223302	-244620	-262489	-276555	-286430	-318811	-346109	-371108	-393250	-411784	-357321
NPV	-198856	-221491	-239768	-253953	-264292	-271013	-291418	-307347	-320852	-331929	-340514	-317156

	12	13	14	15	16	17	18	19	20	21	22	23
Payback												
Plant yield	91464	95583	99887	104385	109085	113996	119129	124493	130098	135955	142076	148472
FTE-Credit	-33060	-33060	-33060	-33060								
Regular Credit												
Cumulated Cash Flow	-298917	-236394	-169567	-98242	10842	124839	243968	368461	498559	634514	776590	925062
NPV	-293962	-270973	-248221	-225736	-193896	-163086	-133274	-104427	-76515	-49507	-23373	1914

Payback = 25% on fuel subsidy savings, plant yield (fuel savings – O&M costs).[56]

[56] *For the mathematical formula underlying the subsidy calculation, please consult chapter 8.*

6.2.2. IS 2 – Hot water for cleaning processes in food industry

For this case study a steam boiler system is analyzed. Two oil boilers generate the annual energy consumption of 33,000 MWh. The system is described in the following table:

Table 60: Basic assumptions, yeast industry case (IS2)

Basic data	
Heating system	Heavy fuel No. 2
Boiler efficiency	89%
Thermal capacity installed kWh	17.000
Number of boilers	2
Sector	Industry
Subsector	Food
Products	Yeast
Climate zone	Tunis area
Operation period	24 h/7 days a week/ 335 days per year
Total energy consumption MWh/a	34.001

Table 61: Temperature level for different processes, yeast industry case (IS2)

Temperature level								
Process name	Medium	Supply temperature in °C	Return temperature in °C	Temperature of the process fluid in °C				14.600
Cleaning / CIP	STEAM	170	120	Water	25	85	3.417	MWh/a

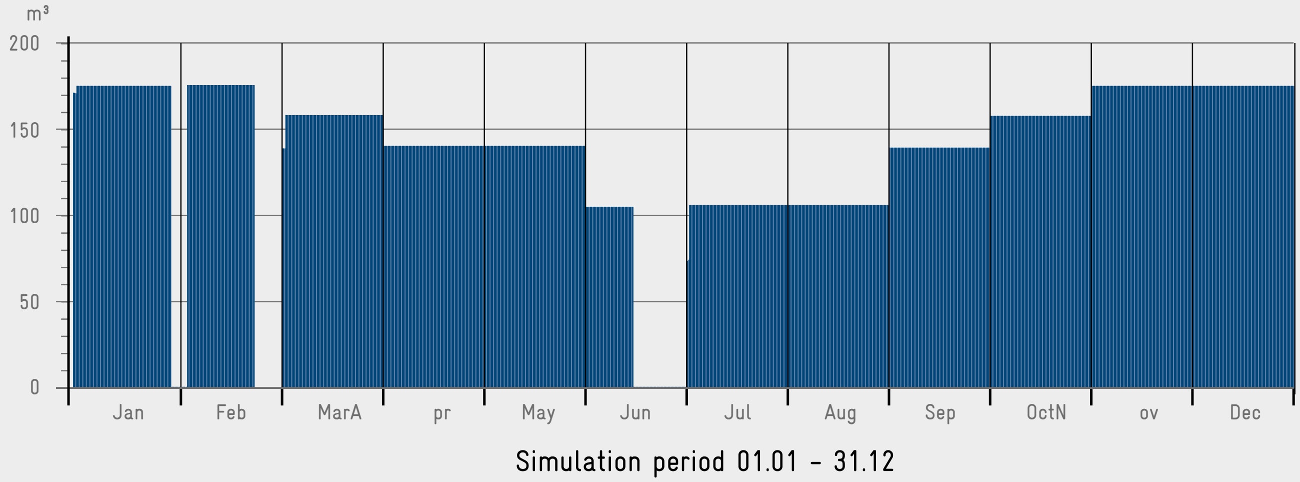
The solar system is connected directly to the cleaning in process (CIP) system; this is a very good example for process level integration. The heat needed for the CIP system is around 3,400 MWh per year. The monthly profile was given as follows:

Table 62: Monthly profile of steam demand, yeast industry case (IS2)

Profile in % of the annual demand												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
10	10	9	8	8	6	6	6	8	9	10	10	100

The factory does not operate for the whole year; there are some days without heat demand. This is represented by the following bars:

Figure 50:
Annual steam consumption profile, yeast industry case (IS2)



Since water is heated up by the solar system and CIP water can be stored easily, it is not important to know the actual hourly heat level. The assumption is that the overall daily and hourly heat demand profile of the CIP-process is constant due to storage capacities, although the CIP process itself is not constant but rather subject to fluctuations. Solar energy can be constantly fed into the tank system, except during the production breaks. Since solar energy is produced during the daytime only, hot water has to be stored in order to be available 24 hours/day. The solar system is able to preheat the feed water from 25°C to a maximum of 85°C, which is the target temperature of the CIP system.

6.2.2.1. Results for IS2

Three different scenarios were simulated for this company profile: flat plate collectors (FPC) and linear Fresnel collectors (LFC) at the Tunis location and vacuum tube collectors (CPC) at the Sfax location. The solar loop works with a solar buffer for which a tank optimization is analyzed (see chapter 5 for methodology). In the appendix, the results of all simulations and calculations are listed in detail.

Both technologies FPC and CPC might be used in the Tunis area, since temperatures for the CIP processes are sufficiently low that economic results are nearly the same.

Table 63: Best-case results for different collector technologies and sites, yeast industry case (IS2)

Location	Type	Fuel	Area [m²]	LHC [TD/ MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
Sfax	FPC	HF	500	97,3	-5.677	7,9	20,4	11,2
Tunis	FPC	HF	1000	114,6	-149.904	5,8	26,9	12,9
Tunis	CPC	HF	1000	115,2	-182.553	5,8	27,1	13,0

Tunis CPC

Figure 51:
Sensitivity analysis between collector area and storage tank size to determine system efficiency for vacuum tube collectors (CPC), yeast industry case (IS2)

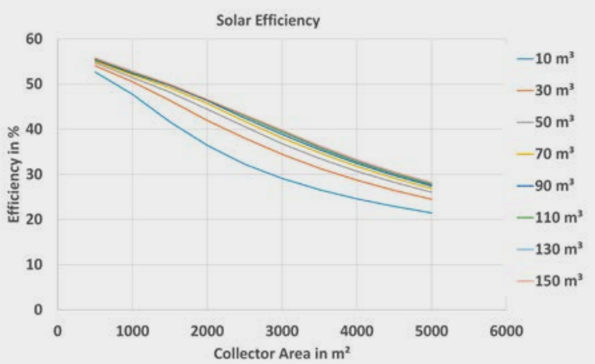
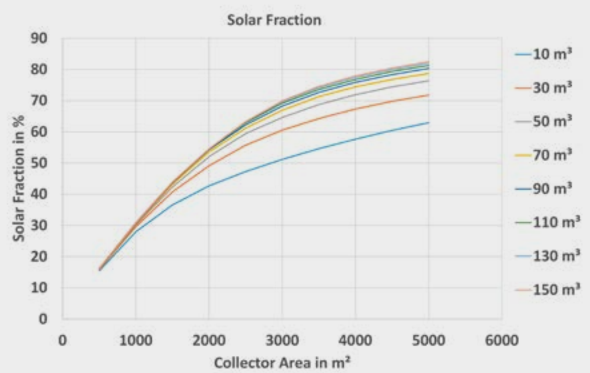


Figure 52:
Sensitivity analysis comparing collector area and storage tank size to determine solar fraction for vacuum tube collectors (CPC), yeast industry case (IS2)



Tunis FPC

Figure 53:
Sensitivity analysis between collector area and storage tank size to determine system efficiency for flat plate collectors (FPC), industrial case (IS2)

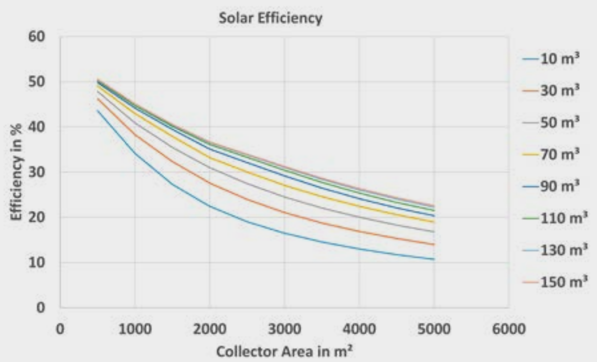
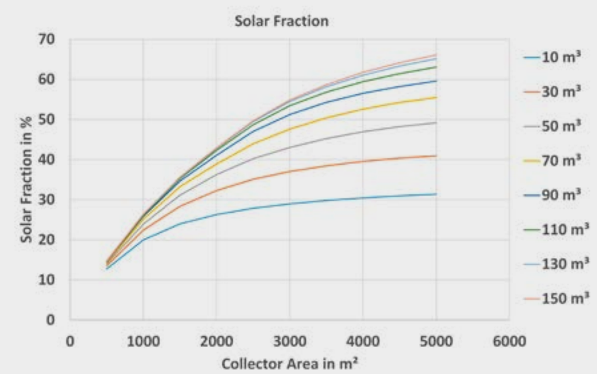


Figure 54:
Sensitivity analysis between collector area and storage tank size to determine the solar fraction for flat plate collectors (FPC), industrial case (IS2)



CPC reveal higher efficiency than FPC in terms of solar fraction, though it does not reach 100% even for the largest systems; this, however, is only a technical and not an economic indicator.

Economic results Tunis area

CPC and FPC do not reach economic viability according to the DPP, though FPC achieve slightly better results.

Table 64: Economic overview for FPC, Tunis area, yeast industry case (IS2)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
500	10	871	114,9	-77.585	5,8	27,0	12,9
1000	70	858	114,6	-149.904	5,8	26,9	12,9
1500	90	789	118,4	-249.741	5,4	28,6	13,3
2000	110	722	123,8	-378.370	4,9	31,2	13,8
2500	110	665	126,7	-481.257	4,6	32,8	14,1
3000	110	608	131,2	-606.921	4,2	35,5	14,6
3500	130	567	135,3	-737.278	3,8	38,2	15,0
4000	130	521	139,7	-860.477	3,4	41,5	15,4
4500	130	481	143,6	-972.659	3,1	44,8	15,8
5000	130	445	146,9	-1.070.734	2,8	48,1	16,2

Table 65: Economic overview for CPC, Tunis area, yeast industry case (IS2)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
500	10	1053	128,7	-162.660	4,5	33,6	14,2
1000	30	1010	115,2	-182.553	5,8	27,1	13,0
1500	50	965	117,1	-288.002	5,6	27,9	13,2
2000	70	915	119,6	-406.541	5,3	29,1	13,4
2500	70	836	124,6	-564.843	4,8	31,6	13,9
3000	90	777	129,5	-737.503	4,4	34,2	14,4
3500	90	709	135,4	-922.599	3,8	37,9	14,9
4000	90	648	141,2	-1.107.377	3,3	42,2	15,5
4500	90	595	146,5	-1.276.957	2,9	46,8	16,0
5000	90	549	151,0	-1.425.806	2,5	51,5	16,5

Profitability findings for Sfax area

Profitability is better due to higher irradiation. Nevertheless, with DPP of slightly above 20 years, they just reach payback of capital employed and do not come close to meeting investor expectations.

Table 66: Economic overview for FPC, Sfax area, yeast industry case (IS2)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/ m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
500	10	1029	97,3	-5.677	7,9	20,4	11,2
1000	70	1004	97,9	-16.599	7,8	20,6	11,3
1500	90	926	100,9	-62.649	7,4	21,6	11,6
2000	110	848	105,4	-148.198	6,8	23,2	12,0
2500	110	783	107,7	-213.939	6,6	24,1	12,2
3000	110	717	111,4	-310.207	6,2	25,6	12,6
3500	130	672	114,2	-402.164	5,8	26,8	12,9
4000	130	619	117,7	-505.974	5,5	28,4	13,2
4500	130	571	121,0	-604.203	5,1	30,0	13,6
5000	130	528	123,7	-690.614	4,8	31,4	13,9

Sensitivity analysis for best-case in Sfax

To reach a SPP of five years, the following requirements would need to be met:

- **grant subsidies of 700 TD/m² (almost five times the current incentive, 74% of investment costs), or**
- **energy price increase rate of 55% per year (current assumption: 10-5%), or**
- **fuel price level of 130 TD/MWh (currently only 45 TD/MWh)**

Figure 55:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Sfax area with flat plate collectors (FPC), industrial case (IS2)

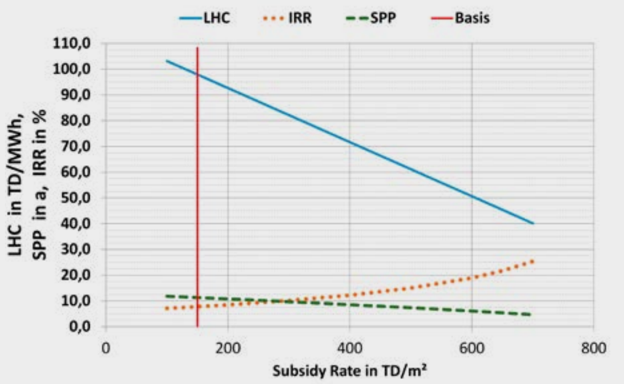


Figure 56:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Sfax area with flat plate collectors (FPC), industrial case (IS2)

Figure 57:
Sensitivity analysis of relative fuel price changes (%) on LHC, IRR, SPP, Sfax area with flat plate collectors (FPC), industrial case (IS2)

Excursus: Results for subsidy mechanism FTE (ANME)

As described in the excursus in chapter 5, this mechanism changes the boundary conditions for financing and subsidies. There is a subsidy of TD 150/m² collector area on the investment. In addition there are soft loans of 2% for 25% of the investment for 15 years, including five years grace period, and of 5% for 45% of the investment for 10 years.

Table 67: Assumptions FTE subsidy model IS 2

Assumptions	Value	Unit
Price before subsidy	85	TD/MWh
Price after subsidy	45	TD/MWh
Increase rate factor years 1-6	110,0%	
Increase years 7-20	105,0%	
Increase rate factor for gas price before subsidy	100,0%	
Degradation factor	99,5%	
Discount factor	107,0%	
Solar yield (TS 1,1-1,4 IS 0,8-1)	1	MWh/m² coll.area
Boiler efficiency	85%	

The solar savings result in TD 161/MWhm² collector area for fuel oil, if the solar system was installed in year one. In the calculation, the grant is increased. The values for Sfax vary between approximately 0.8 und 1 MWh/m². If multiplied by 25% this would result in additional support of TD 40.25/m² collector area.

The total support of the system varies between 32% and 37%, depending on size and thus on efficiency levels as well as on overall costs.

For the calculations of the IRR, annual savings have been discounted over 20 years with the variable discount factor until the residual sum correlates to the remaining investment sum.

The calculation of the DPP has been discounted with the interest on capital rate of 8% and totalled to correlate with the remaining investment sum.

For the calculation of the SPP, annual savings have been totalled until the sum of the NPV corresponds to the residual investment sum. It can therefore not be calculated via generic formulas and is given for the best-case only.

Result

If calculated under the assumptions above, the second best IRR results in 11% and the best DPP is 14.5 years for a 1000 m² system. Since the IRR is only 0.1% worse than the best-case but twice as big, this was chosen.

Table 68: Subsidy mechanism FTE, economic overview for FPC, Sfax area, feed water preheating (IS2)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]
500	10	1029	77,3	92.123	11,1	14,4
1000	70	1004	77,7	175.635	11,0	14,5
1500	90	926	80,1	211.092	10,5	15,2
2000	110	848	83,7	199.811	9,9	16,2
2500	130	795	85,7	197.689	9,6	16,7
3000	130	733	87,8	173.978	9,3	17,3
3500	130	672	90,6	123.077	8,8	18,2
4000	130	619	93,4	64.368	8,4	19,1
4500	150	578	95,7	10.047	8,1	19,9
5000	150	537	97,5	-34.651	7,8	20,5

For this best-case the investment assumptions are shown in the following table.

Table 69: Investment for best-case FTE subsidy scheme, best-case FPC

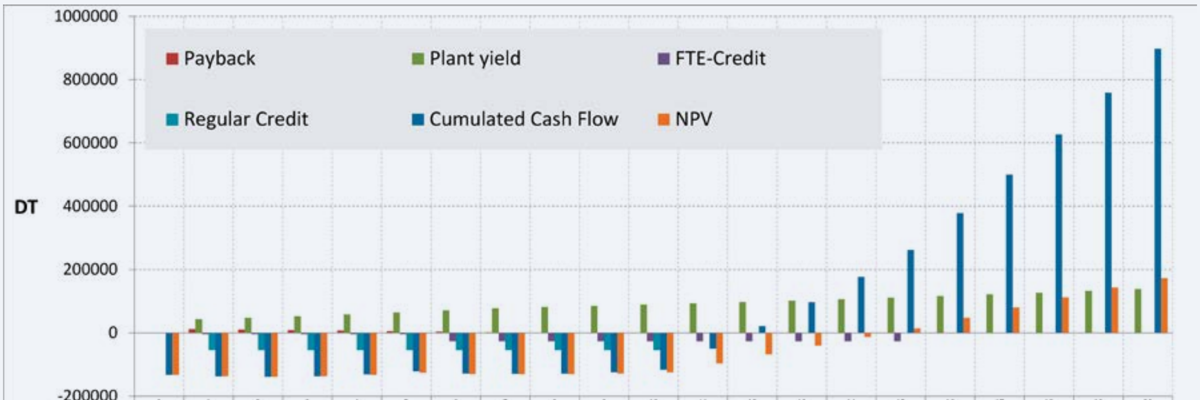
Item	TD	Planned	Contribution to investment in %
Total cost	943600	100%	
Subsidy grant (150 TD/ m²):	150000		15,9%
Equity	133080	30%	
Soft loan FTE (2% interest rate / 5 years grace period	235900	25%	10,3%
Soft loan (5% interest rate)	424620	45%	5,9%
Additional income by saved subsidies (140 TD/m²) * 0,25	40250		4,3%
Total subsidy			36,4%
Changed SPP due to FTE mechanism		12,6 years vs. 11,2 years (without FTE)	
Improved DPP due to FTE mechanism		14,5 years vs. 20,4 years (without FTE)	

The investment grant reduces the equity accordingly and represents 15,9% of the investment.

The following cash flow model allows achievement of the SPP after year 12, which is later than without the FTE support.[57] The effects on DPP are striking, with an improvement of nearly six years compared to the equity only case. The total subsidy increases to 36.4% instead of 15.9% in the equity only case.

[57] *The calculation of the SPP is case-specific and therefore cannot be provided in the table for all cases.*

Figure 58:
Cash flow simulation for best-case scenario FTE ANME subsidy scheme for IS2



	0	1	2	3	4	5	6	7	8	9	10
Payback	0	11816	10435	8935	7306	5535	3609	1513	369		
Plant yield	0	43147	47707	52719	58225	64275	70919	78215	81731	85405	89244
FTE-Credit	0	-4718	-4718	-4718	-4718	-4718	-26262	-26262	-26262	-26262	-26262
Regular Credit	0	-54990	-54990	-54990	-54990	-54990	-54990	-54990	-54990	-54990	-54990
Cumulated Cash Flow	-133080	-137825	-139391	-137446	-131623	-121522	-128246	-129769	-128921	-124768	-116776
NPV	-133080	-137473	-138816	-137272	-132992	-126117	-130355	-131243	-130785	-128708	-125006

	11	12	13	14	15	16	17	18	19	20
Payback										
Plant yield	93256	97447	101827	106404	111186	116184	121405	126862	132563	138521
FTE-Credit	-26262	-26262	-26262	-26262	-26262					
Regular Credit										
Cumulated Cash Flow	-49782	21403	96968	177111	262035	378219	499624	626486	759049	897570
NPV	-96273	-68005	-40219	-12934	13838	47750	80563	112310	143026	172745

Payback = 25% on fuel subsidy savings, plant yield (fuel savings – O&M costs).[58]

6.2.3. IS 3 – Steam generation in textile industry

For this case study a steam boiler system is analyzed. Two gas boilers generate the steam used for processes in the textile industry. The system is described in the following table:

Table 70: Basic assumptions, textile industry case (IS3)

Basic data	
Heating system	Natural gas
Boiler efficiency	92%
Thermal capacity installed kWh	14.490
Number of boilers	2
Sector	Industry
Subsector	Textile
Climate zone	Tunis area
Operation period	15 h/6 days a week/ 282 days per year
Total steam consumption MWh/a	12.600

[58] *For the mathematical formula for the subsidy calculation, please consult chapter 8.*

The monthly and weekly profile was given:

Table 71: Monthly profile of steam demand, textile industry case (IS3)

Profile in % of the annual demand (in sum 100%)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	total
8,0	8,0	10,0	9,0	9,0	7,5	8,5	2,0	9,0	10,0	10,0	8,0	100

Table 72: Weekly profile of steam demand, textile industry case (IS3)

Profile in % of the weekly demand							
Mon	Tue	Wed	Thu	Fri	Sat	Sun	total
15	20	20	20	15	10	0	100

Since the factory runs in two shifts, process heat is needed 15 hours a day, while none is needed during night-time.

Due to partial load and standby times, the average boiler efficiency throughout the year is assumed to be 75% instead of the maximum achievable efficiency of 92%. The boilers generate approximately 12,600 MWh heat per year, which corresponds to 19,000 tons of steam.

The solar system directly generates steam, which cannot be stored. Due to this boundary condition, solar heat production has to be lower than the demand at any given time of the year. If this is not the case the solar system has to be reduced to the demand level. The solar system is integrated in parallel to the steam boilers.

Steam is provided at a temperature of 165°C; steam condensate returns at a temperature of 90°C. The heating process needs 300 kJ/kg and the vaporization process 2000 kJ/kg. The result is that most of the energy is needed for vaporization at a temperature level of 165°C.

6.2.3.1. Results for IS3

Three different cases were simulated for the locations Tunis and Sfax. The fuel source is natural gas. The Tunis case study applies both vacuum tube collectors (CPC) and linear Fresnel collectors (LFC). The solar loop works without solar buffer but with a kettle type steam generator (see chapter 5 for methodology), so no tank optimization is executed. In the appendix, the results of all simulations and calculations are listed in detail.

Table 73: Best-case results for different collector technologies and sites, textile industry case (IS3)

Location	Type	Fuel	Area [m²]	LHC [TD/MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
Sfax	LFC	NG	4400	174,4	-2.562.554	< 0	> 100	21,4
Tunis	LFC	NG	4400	208,4	-3.028.975	< 0	> 100	26,3
Tunis	CPC	NG	10000	326,9	-2.934.541	< 0	> 100	39,0

Table 74: Irradiation difference Tunis vs. Sfax

Irradiation	Tunis	Sfax
Global horizontal/kWh/m²	1800	1992 (+11%)
Direct horizontal/kWh/m²	1090	1286 (+18%)

Since linear Fresnel collectors only work with direct horizontal irradiation (DHI),[59] differentiation is necessary when using this technology, as it tracks the sun. In Sfax, DHI is considerably higher (by 18%), so the Fresnel yield will be higher in Sfax. The best economic results for LFC are therefore in Sfax.

Figure 59:
Solar fraction and solar efficiency by collector area for linear Fresnel collector (LFC), industrial case (IS3), Tunis and Sfax areas compared

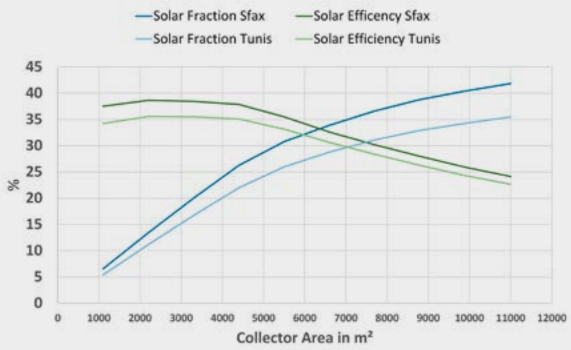
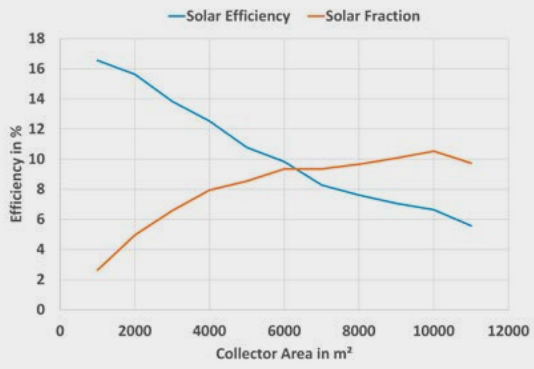


Figure 60:
Solar fraction and solar efficiency over collector area for vacuum tube collectors (CPC), industrial case (IS3), Tunis area



Results for CPC collector in Tunis area

At a supply-level temperature of 165°C, CPC have considerably higher losses than LFC, which explains their lower solar fraction and is also reflected in lower economic results. With a SPP of more than 36.8 years in Tunis the CPC case is not at all economic and far below investor expectations. IRR and NPV are negative for all cases.

[59] *DHI is the irradiation component that reaches the horizontal surface of the earth without any atmospheric losses from scattering or absorption, see also http://solargis.info/doc/solar-and-pv-data, comp. 15 April 2015)*

Table 75: Economic results for vacuum tube collectors (CPC), industrial case (IS3), Tunis area

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
1000	0	331	354,2	-823.652	< 0	> 100	36,8
2000	0	311	350,4	-1.525.624	< 0	> 100	36,7
3000	0	275	366,5	-2.148.316	< 0	> 100	38,6
4000	0	249	372,0	-2.643.079	< 0	> 100	39,6
5000	0	214	394,0	-3.064.632	< 0	> 100	42,6
6000	0	196	389,1	-3.304.910	< 0	> 100	42,7
7000	0	168	404,7	-3.478.539	< 0	> 100	45,6
8000	0	151	393,9	-3.463.590	< 0	> 100	45,4
9000	0	140	366,0	-3.278.735	< 0	> 100	42,9
10000	0	132	326,9	-2.934.541	< 0	> 100	39,0
11000	0	110	315,2	-2.571.244	< 0	> 100	39,5

Results for linear Fresnel collectors (LFC) in Tunis and Sfax area

With a SPP of around 26.3 years in Tunis and 21.4 years in Sfax, even the best LFC case is not at all economic and far below investor expectations. IRR and NPV are negative for all cases.

Table 76: Economic results for linear Fresnel collectors (LFC), industrial case (IS3), Tunis area

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
1100	0	615	339,3	-1.586.777	< 0	> 100	49,3
2200	0	632	216,8	-1.644.906	< 0	> 100	27,5
3300	0	631	211,5	-2.359.700	< 0	> 100	26,7
4400	0	624	208,4	-3.028.975	< 0	> 100	26,3
5500	0	591	214,1	-3.763.488	< 0	> 100	27,2
6600	0	547	225,1	-4.553.434	< 0	> 100	29,0
7700	0	506	236,2	-5.328.451	< 0	> 100	30,9
8800	0	469	247,5	-6.085.475	< 0	> 100	32,9
9900	0	434	259,4	-6.821.043	< 0	> 100	35,2
11000	0	405	269,5	-7.495.923	< 0	> 100	37,4

Table 77: Economic results for linear Fresnel collectors (LFC), industrial case (IS3), Sfax area

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
1100	0	747	279,4	-1.460.175	< 0	> 100	36,9
2200	0	760	180,3	-1.398.981	< 0	> 100	22,2
3300	0	757	176,4	-1.998.559	< 0	> 100	21,7
4400	0	746	174,4	-2.562.554	< 0	> 100	21,4
5500	0	701	180,6	-3.236.620	< 0	> 100	22,3
6600	0	644	191,1	-3.993.159	< 0	> 100	23,8
7700	0	597	200,4	-4.721.706	< 0	> 100	25,2
8800	0	553	209,8	-5.437.193	< 0	> 100	26,7
9900	0	513	219,7	-6.143.402	< 0	> 100	28,3
11000	0	478	228,4	-6.796.862	< 0	> 100	29,8

Sensitivity analysis for LFC best-case in Sfax

The results show that LFC systems would need considerably higher subsidy support or massively increased energy prices in order to become profitable.

To reach a SPP of five years the following requirements would need to be met:

- **grant subsidies of 1000 TD/m² (over 6 times the current incentive, over 90% of investment costs), or**
- **energy price increase rate of 70% per year (current assumption: 10-5%), or**
- **fuel price level of 175 TD/MWh (currently only 38 TD/MWh)**

Figure 61:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Sfax area with linear Fresnel collector (LFC), industrial case (IS3)

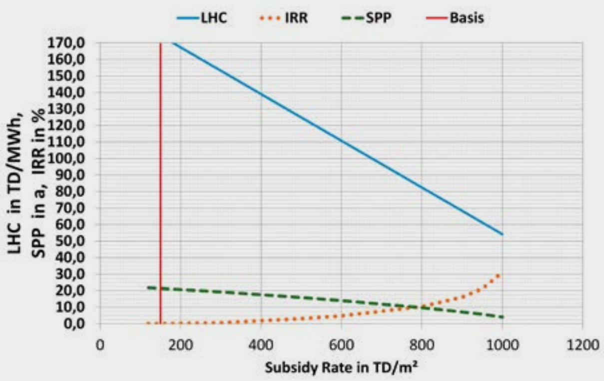


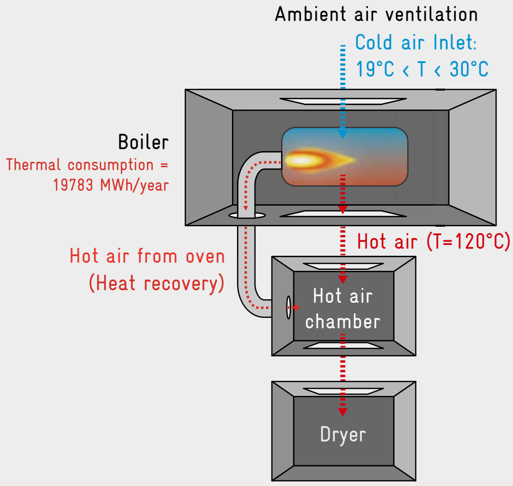
Figure 62:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Sfax area with linear Fresnel collector (LFC), industrial case (IS3)

Figure 63:
Sensitivity analysis of relative fuel price changes (%) on LHC, IRR, SPP, Sfax area with linear Fresnel collector (LFC), industrial case (IS3)

6.2.4. IS 4 – Hot air processing for drying in brick industry

This case study analyses a drying process that is typical for the brick industry. The schematic process diagram looks as follows:

Figure 64:
Schematic diagram of drying process



During the process, the ambient air has to be heated up to 120°C with a gas burner. The hot air is blown into the drying chamber. Since the exhaust of the burner is used directly in the process, the efficiency of the burner is considered to be 100%. A portion of the hot air can be reused through heat recovery circulation.

The system is in operation day and night, with the exception of two weeks per year.

Table 78: Basic assumptions, brick industry case (IS4)

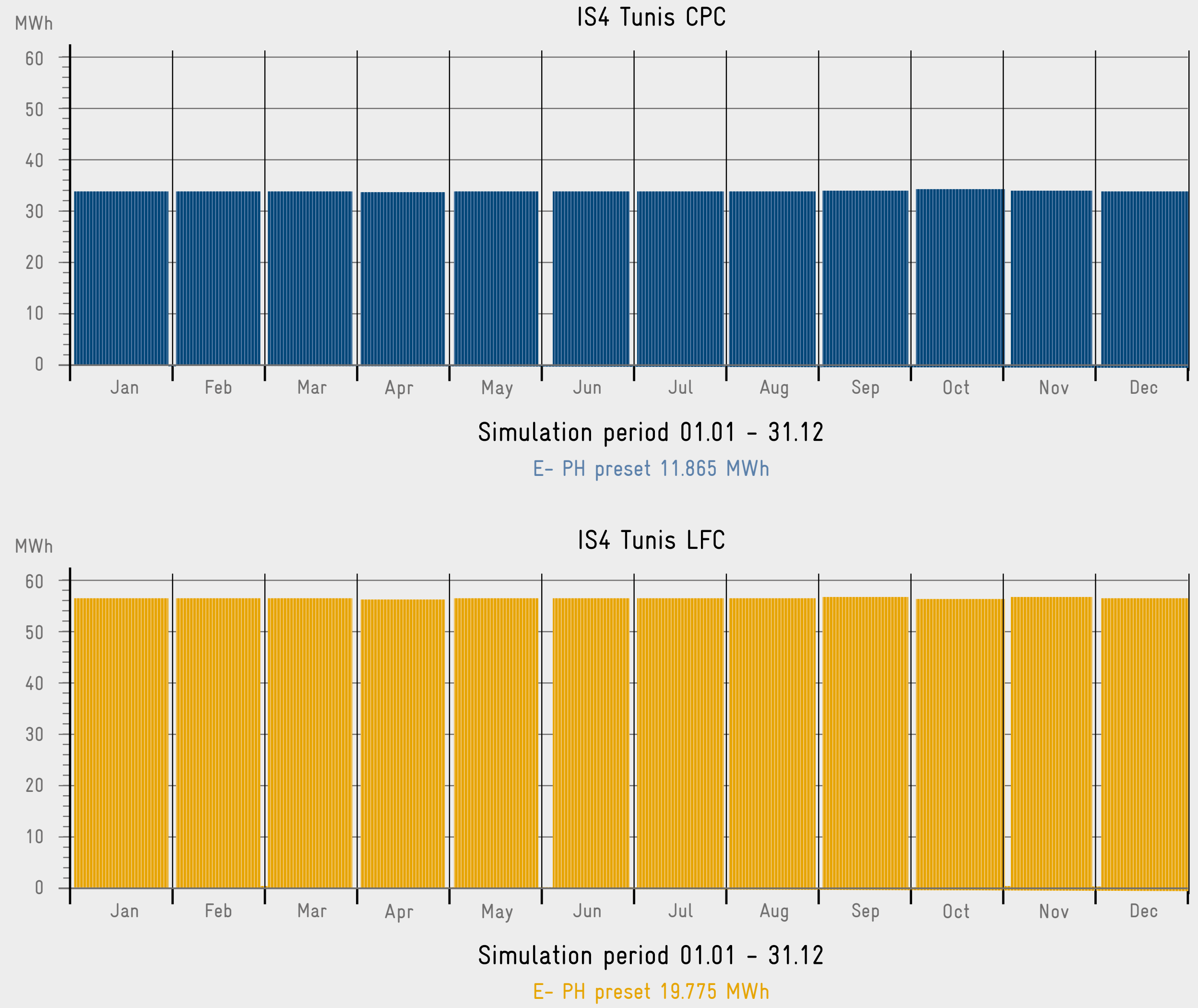
Basic data	
Heating system	Natural gas
Boiler efficiency	100%
Number of boilers	1
Sector	Industry
Subsector	Bricks
Climate zone	Tunis area
Operation period	24 h/7 days a week/ 350 days per year
Total fuel consumption MWh/a	19.786

The solar system which fits best from a technical point of view is the Fresnel collector, because it can heat the water up to 160°C without a major decline in efficiency. The typical water/air heat exchanger needs a temperature difference of 40 Kelvin, which means that the 160°C-water generates hot air at 120°C, which is the desired temperature level. With this kind of application it would be more complicated to produce steam.

The use of a non-concentrating vacuum tube collector is also possible, but this would limit the outlet temperature to around 120°C or significantly reduce the efficiency. This means that the contribution of the CPC collector would only be 60% compared to the Fresnel collector. This has to be taken into account when comparing results.

The simulations are therefore based on two different profiles:

Figure 65: Heat generation output of CPC and LFC technologies, brick industry case (IS4)



6.2.4.1. Results for IS4

Three different cases were simulated for the locations Tunis and Sfax. The fuel source is natural gas. The Tunis case study applies both vacuum tube collectors (CPC) and linear Fresnel collectors (LFC). The solar loop works with a solar buffer for which a tank optimization is analysed (see chapter 5 for methodology). The solar buffer is supposed to power the air conditioning using a heat exchanger. In the appendix, the results of all simulations and calculations are listed in detail.

Table 79: Best-case results for different collector technologies and sites, brick industry case (IS4)

Temp. level	Location	Type	Fuel	Area [m²]	LHC [TD/ MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
60°C-120°C	Tunis	CPC	NG	4800	111,9	-1.493.388	2,2	57,4	16,9
60°C-160°C	Sfax	LFC	NG	11000	109,6	-4.420.916	1,6	69,8	17,8
60°C-160°C	Tunis	LFC	NG	9900	128,1	-4.872.150	< 0	> 100	21,0

While LFC can provide the entire temperature range up to 160°C, CPC can only provide preheating up to 120°C with a 40% lower demand. For the interpretation of the solar fraction this has to be considered.

Results for linear vacuum tube collectors (CPC) in Tunis:

Figure 66: Sensitivity analysis between collector area and storage tank size to determine system efficiency for vacuum tube collectors (CPC), industrial case (IS4), Tunis area

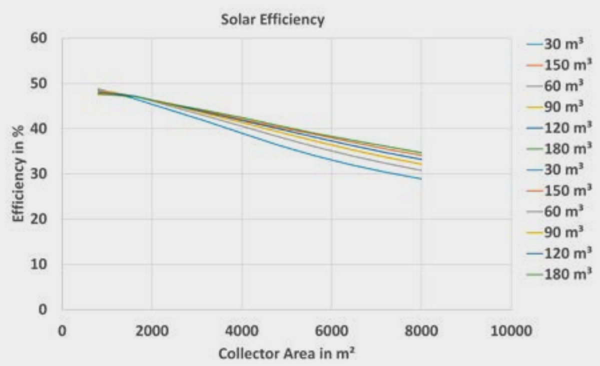


Figure 67: Sensitivity analysis between collector area and storage tank size to determine the solar fraction for vacuum tube collectors (CPC), brick industry case (IS4), Tunis area

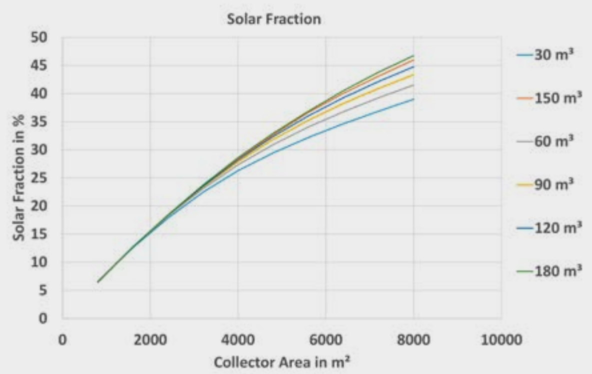


Table 80: Economic results for vacuum tube collectors (CPC), brick industry case (IS4), Tunis area

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/ m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
800	30	976	136,1	-496.137	0,1	> 100	19,9
1600	30	935	120,9	-735.327	1,4	79,4	18,0
2400	30	885	118,1	-988.648	1,6	70,8	17,7
3200	30	834	116,4	-1.198.851	1,7	66,5	17,5
4000	30	781	115,4	-1.373.767	1,8	64,5	17,4
4800	60	765	111,9	-1.493.388	2,2	57,4	16,9
5600	60	722	115,6	-1.784.247	1,8	65,5	17,4
6400	90	710	119,3	-2.162.945	1,4	76,6	17,9
7200	90	675	124,6	-2.560.110	0,9	> 100	18,6
8000	120	664	127,9	-2.966.203	0,6	> 100	19,1

Results for linear Fresnel collectors (LFC) in Tunis

Figure 68:
Sensitivity analysis between collector area and storage tank size to determine system efficiency for linear Fresnel collectors (LFC), industrial case (IS4), Tunis area

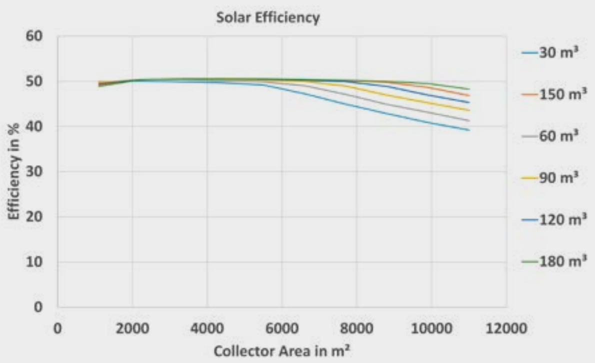


Figure 69:
Sensitivity analysis between collector area and storage tank size to determine the solar fraction for linear Fresnel collectors (LFC), industrial case (IS4), Tunis area

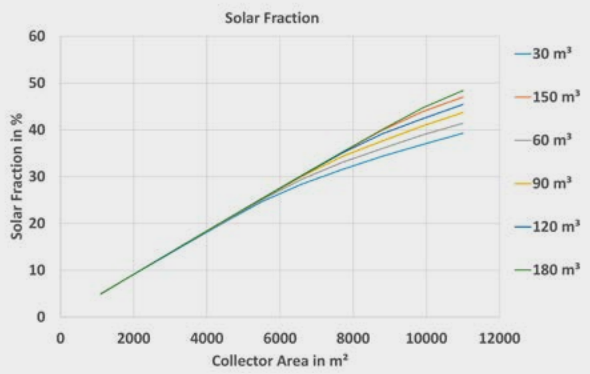


Table 81: Economic results for linear Fresnel collectors (LFC), brick industry case (IS4), Tunis area

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/ m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
1100	30	897	233,0	-1.533.687	< 0	> 100	42,9
2200	30	902	149,8	-1.521.010	< 0	> 100	24,9
3300	30	900	144,5	-2.126.557	< 0	> 100	24,0
4400	30	897	140,3	-2.667.024	< 0	> 100	23,2
5500	30	889	137,2	-3.161.307	< 0	> 100	22,7
6600	60	885	135,7	-3.693.885	< 0	> 100	22,4
7700	90	884	133,3	-4.150.063	< 0	> 100	22,0
8800	120	882	130,6	-4.537.445	< 0	> 100	21,5
9900	150	879	128,1	-4.872.150	< 0	> 100	21,0
11000	180	872	129,4	-5.485.398	< 0	> 100	21,3

For the Tunis location, CPC provide slightly better economic results than LFC, but neither are profitable.

As a comment, the optimal suitable system sizes are differ based on the varying amount energy provision:

CPC: 4800 m², 3500 MWh
LFC: 9900 m², 8000 MWh

Table 82: Economic results for linear Fresnel collectors (LFC), brick industry case (IS4), Sfax area

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/ m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
3300	30	1061	122,6	-1.778.017	0,1	> 100	19,9
4400	30	1059	118,8	-2.199.855	0,5	> 100	19,3
5500	30	1049	116,2	-2.584.772	0,8	> 100	18,9
6600	70	1053	114,6	-3.005.971	1,0	> 100	18,6
7700	150	1064	113,6	-3.465.561	1,1	89,3	18,4
8800	190	1060	111,7	-3.777.731	1,3	78,6	18,1
9900	230	1056	109,7	-4.029.013	1,5	70,1	17,8
11000	230	1046	109,6	-4.420.916	1,6	69,8	17,8
12100	230	1018	111,8	-4.995.978	1,3	79,6	18,1
13200	230	984	115,0	-5.660.018	0,9	100,0	18,7

Figure 70:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Sfax area with linear Fresnel collector (LFC), industrial case (IS4)

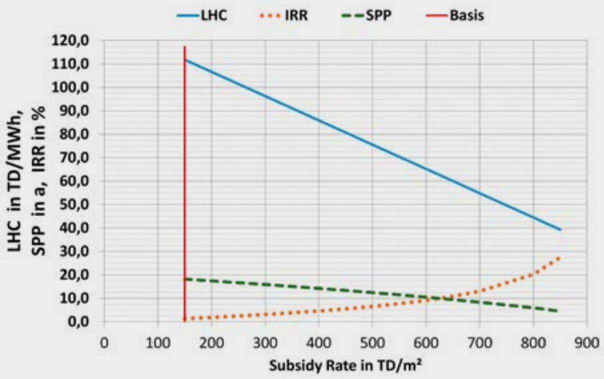


Figure 71:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Sfax area with linear Fresnel collectors (LFC), industrial case (IS4)

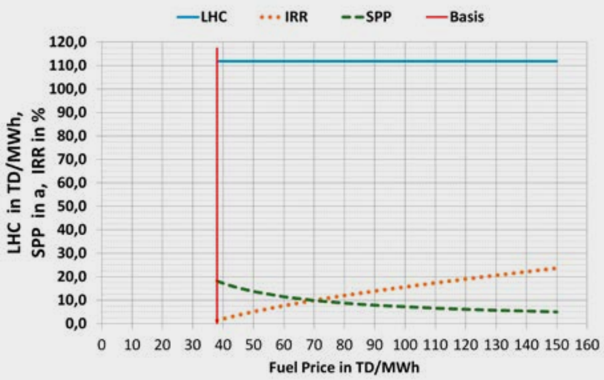
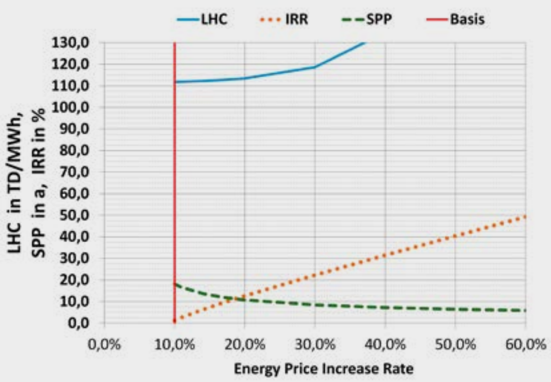


Figure 72:
Sensitivity analysis of relative fuel price changes (%) on LHC, IRR, SPP, Sfax area with linear Fresnel collector (LFC), industrial case (IS4)



Sensitivity analysis for linear Fresnel collectors (LFC) best-case in Sfax

LFC systems would need considerably higher subsidy support or massively increased energy prices in order to become profitable.

To reach a SPP of five years the following requirements would have to be met:

- **grant subsidies of min. 850 TD/m² (over five times the current rate, 80% of investment costs), or**
- **energy price increase rate of more than 60% per year (current assumption: 10-5%), or**
- **fuel price level of min. 150 TD/MWh (currently only 38 TD/MWh)**

6.2.5. Summary on industrial sector

The following table sums up the best economic results of the presented case studies:

Table 83: Best economic cases for the industrial sector

ID	Case	Demand	Temp. Level	Loca-tion	Type	Fuel	Area [m²]	LHC [TD/MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
IS2	Food	Hot water for CIP-process	25°C -85°C	Sfax	FPC	HF	500	97,3	-5.677	7,9	20,4	11,2
IS2	Food	Hot water for CIP-process	25°C -85°C	Tunis	FPC	HF	1000	114,6	-149.904	5,8	26,9	12,9
IS2	Food	Hot water for CIP-process	25°C -85°C	Tunis	CPC	HF	1000	115,2	-182.553	5,8	27,1	13,0
IS1	Food	Feed water preheating	45°C-105°C	Sfax	CPC	NG	1050	115,7	-297.500	4,4	33,8	14,3
IS1	Food	Feed water preheating	45°C-105°C	Tunis	CPC	NG	1050	133,2	-411.941	2,8	47,9	16,1
IS4	Bricks	Air heating	60°C-120°C	Tunis	CPC	NG	4800	111,9	-1.493.388	2,2	57,4	16,9
IS4	Bricks	Air heating	60°C-160°C	Sfax	LFC	NG	11000	109,6	-4.420.916	1,6	69,8	17,8
IS4	Bricks	Air heating	60°C-160°C	Tunis	LFC	NG	9900	128,1	-4.872.150	< 0	> 100	21,0
IS3	Textile	Steam generation	90°C-165°C	Sfax	LFC	NG	4400	174,4	-2.562.554	< 0	> 100	21,4
IS1	Food	Feed water preheating	45°C-105°C	Tunis	LFC	NG	1980	181,6	-1.339.295	< 0	> 100	24,1
IS3	Textile	Steam generation	90°C-165°C	Tunis	LFC	NG	4400	208,4	-3.028.975	< 0	> 100	26,3
IS3	Textile	Steam generation	90°C-165°C	Tunis	CPC	NG	10000	326,9	-2.934.541	< 0	> 100	39,0

6.2.5.1. Influence of technical aspects on profitability

Temperature level
The case studies demonstrate that economic viability varies with the temperature level at which solar thermal energy is integrated into the process. The higher the temperature of the solar provided energy, the less favourable the economic results are. This is due to the effect of thermal losses and the higher investment costs for medium temperature collectors.

Before a decision about the type of collector technology applied is made, the special boundary conditions for the respective company case have to be analyzed by a detailed energy audit and using specific system engineering.

Size of the installation
The results show that the solar system should be dimensioned to cover a low share of the heat demand (base load) in order to reach the best economical results. Bigger installations may provide higher solar fractions (= solar energy/company heat demand) and higher primary energy savings, but profitability drops significantly due to lower efficiency.[60]

Solar technology
In the overall comparison of cases, results show that low temperature collectors can reach the best economical results. However, the most economical technology solution for a specific company case is determined by the availability and complexity of solar integration points and the process temperature levels required. High complexity or risks of process level integration can impede the economic advantage of low temperature collectors for specific cases.

[60] *Bigger systems contain the risk of solar energy dumping when energy demand is low, and thus the waste of unused energy. In addition, the temperature of the heat liquid increases as it flows through each collector in the row, so that the last collectors have to increase the temperature to higher levels and lose efficiency in the process.*

Concentrating solar thermal systems (LFC) have efficiency advantages at higher temperatures and are unrivalled when steam is needed, since the efficiency of non-concentrating collectors drops with rising temperatures. For economical reasons, FPC should not be applied at temperatures higher than 80°C, CPC at temperatures of no more than 120°C. The advantages of concentrating collectors increase with the level of direct irradiation (DHI) on site, which is usually highest in arid regions with a clear atmosphere (low dust/water vapour/emission particles).

Non-concentrating systems have advantages for process level integration, where temperature levels are very often below 100°C. Since they are technically less complex and require less support equipment, non-concentrating system are economical even at small system sizes of less than 1000 m². For temperatures below 80°C, FPC technology usually provides the best economical results, while for temperatures up to 120°C, CPC is most economical.

6.2.5.2. Influence of economic assumptions on profitability

The profitability of solar thermal systems in the industry is mainly determined by the cost of fossil fuels to be replaced (fuel cost savings) and by the investment costs of the solar system (grant subsidy scheme).

Under the given economic assumptions of the study, none of the simulated systems was profitable (NPV remains negative, IRR below capital interest of 8%). None even came close to reaching investor expectations of SPP <= 5 years. To reach this level, current energy prices would have to triple or quadruple, or current investment grant subsidies (150 TD/m²) would have to be increased five- or six-fold, depending on the case.

If solar systems were to be introduced under current economic boundary conditions and assumptions, financial grant support would have to be increased to at least 75% of the investment cost. With decreasing energy subsidies, this support could be diminished correspondingly.

In addition, the assumed energy price increase scenario has clear implications for the economical equation. The study currently assumes a fossil energy price increase scenario of 10% p.a. in year 1-6 and of 5% p.a. in subsequent years. If the energy price increase were to be slowed down or stopped during several years (due to revised energy subsidy policies for example), the economic results would worsen noticeably. In order to reach investor expectations, energy prices would have to increase by 55-70% p.a.

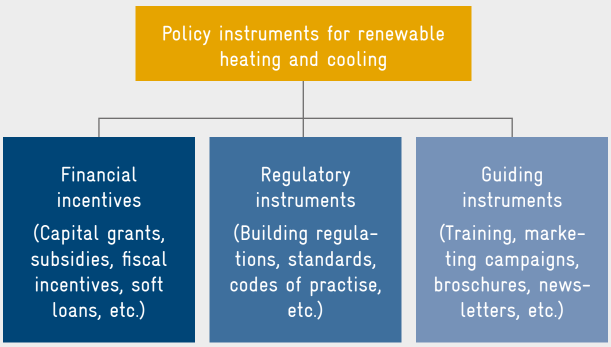
7. Support schemes for renewable heating and cooling

A variety of support options exist to promote the use of heating and cooling technologies.

These can be separated into

- financial incentives that improve the profitability of a given technology
- regulatory instruments that create a positive framework for the use of renewable energies
- flanking measures that are necessary to create awareness as well as guarantee the smooth and effective integration of such technologies.

Figure 73:
Policy instruments for renewable heating & cooling



Source: IEA[61]

7.1. Financial incentive schemes for solar thermal systems

Financial incentive schemes (FIS) have to be introduced to enhance the economic competitiveness of a given technology. Solar thermal has the disadvantage that the entire investment costs for the 20 to 30 years of operation have to be made with installation, while operation and maintenance costs only have a very low impact. Therefore, reducing upfront or financing costs can have important impacts on increasing the attractiveness of the investment in solar thermal.

Important FIS can be:[62]

- grants (direct support to investment)
- tax reductions (direct and indirect taxes)
- loans at reduced rates
- RES production bonus
- tradable certificate schemes

[61] *http://www.iea.org/publications/freepublications/publication/renewable_heating_cooling_final_web.pdf, 15 Jan. 2015*

[62] *http://www.erec.org/projects/finalised-projects/k4-res-h/key-issue-4.html, 18. Nov. 2014*

Table 84: Incentivizing policy instruments to support renewable heating and cooling

Instrument	Description / example	Addresses which problems?	Risks
Grants	One-time subsidy up to the investment (% of investment, lump sum, rebate)	Reduces demand for debt financing and equity	Not reliable due to status of public budget Not necessarily quality related (equipment/installation) May be too low as incentive
	Grant divided into instalments	Increases quality level of installations	Supervision difficult
Bonus model	Based on size	Lower m² utilization rate	Not reliable due to status of public budget Quality of system/ installation
	Based on output (kWh)	Quality of equipment/installation	Difficulties to measure if not supervised by investor – measuring vs. estimating Must be related to demand
Soft loans	Subsidy to bank loan	High upfront investment for long-term renewable technologies with high upfront costs	Small systems are often financed from equity Administrative procedures have to be solved
Tax reductions	Immediate or long-term reduction of certain taxes	Reduces upfront costs Might be tradable	Interesting for companies with positive net results only

7.2. Regulatory instruments

Generally implemented by means of regulation, governments can intervene in the market by imposing requirements on specified sectors. The legal and administrative costs of political incentives are often kept to a minimum for governments, although monitoring and enforcement may be required at local or regional level.[63] Nevertheless, regulatory instruments might become a financial burden for all those investors who are willing to make a certain investment. If they cause high financial or technical hurdles, they might therefore lead to postponements of or distraction from investment decisions. Therefore, it seems to be easiest to enforce new regulations for new buildings in the heating and cooling sector or to offer generous exemptions for existing building stock, if applicable.

[63] *http://www.iea.org/publications/freepublications/publication/renewable_heating_cooling_final_web.pdf, 15 Jan. 2015*

Table 85: Regulative policy instruments to support renewable heating & cooling

Instrument	Description / example	Addresses which problems?	Risks
Building regulations	Focus on new buildings/ major refurbishments	Lower planning and execution costs in planning stage than during refurbishments	Enforcement of the measure not clear Might inhibit investments Must be well designed to be executable
Standards	Set high standards to phase out energy inefficient technologies	Cheap, inefficient products in the market with low up-front costs	Enforcement Measures must be regularly adapted to have an effect

For the moment, no obligations exist in Tunisia to use solar thermal or other renewable energies when constructing new buildings or refurbishing old ones. What do exist are minimum requirements for "Qualisol" collectors, which is the local "Solar Key Mark" equivalent, to guarantee minimum energy yield of the collectors employed.

7.3. Guidance instruments

Guiding instruments or flanking measures are necessary in the form of:

- feasibility studies that can be used to create confidence with the new technologies when comes to new investments,
- well-documented demonstration projects that serve as technology showcases,
- training and education of planners and installers on technology and marketing, issues to bring technologies into the market with high quality installations,
- adaptation of building codes and technology certificates according to technology requirements,
- media campaigns and marketing to draw public attention to the technological opportunities and economic viability of solar thermal

Table 86: Guidance instruments to support renewable heating & cooling

Instrument	Description / example	Addresses which problems?	Risks
Guidance instruments	Improve quality/outreach of measures	Unknown support programmes Low quality implementation	Have to be designed according to focus group to have effect

Tunisia has already developed a broad scope of different flanking instruments such as energy audits, support to feasibility studies, quality instruments and information via websites and newsletters. This provides a good basis to enforce future programmes.

8. Political recommendations for enhancing the market for large solar thermal installations in Tunisia

Solar thermal technology has a great technical potential for reducing the dependency on fossil fuel imports and for managing the increasing energy demand in Tunisia in an environmentally-friendly manner. The technology is a proven option in the Tunisian residential market and in the tertiary and industrial sectors outside of Tunisia, especially in Europe. Within Tunisia, however, large solar thermal applications have so far not been able to unlock attractive market segments due to a lack of competitiveness with fossil alternatives.

Competitiveness can be improved by changes in subsidy policies, financing instruments, market information and by developing the technology towards a more efficient deployment of planning, installation and operation in some sectors. These recommendations indicate the way towards a more solar thermal friendly regulation and offer support toward exploring the potentials in the short- to miTDerm future.

It must be pointed out that the precondition for market development in any sector is a drastic reduction of fossil fuel subsidies, as well as the increase of fossil energy prices, ideally to the level of international/ European purchase price levels.

However, recent drops in oil and gas prices might slow down the political will for subsidy reforms, thus leading to less ambitious energy price scenarios.

8.1. Benefits of reducing fuel subsidies by the use of solar thermal

Due to consumption subsidies, the fuel price for consumers in Tunisia still does not reflect the true costs of fuel. Therefore, solar energy savings contribute to subsidy savings for the Tunisian state because a reduction in consumption leads to less spending on subsidies. These can be calculated as benefit in TD per m² of collector area installed. Nevertheless, possible savings through the use of solar thermal systems depend on the efficiency of the conventional system as well as on the yield of each solar thermal system due to technology, irradiation and other effects. As a rule of thumb, it can be said that the less efficient the conventional system, and the more efficient the solar thermal system works, the more subsidies could be saved by using solar thermal.[64]

The data basis of these calculations is shown in the following table with the example of IS2 for gas and heavy fuel.

[64] *Formula for saved subsidies:*
n: operation period of solar plant, i: year of operation
P: current price, Pi: subsidized price
Y: solar yield (first year), η: boiler efficiency
d: degradation factor, q: discount factor

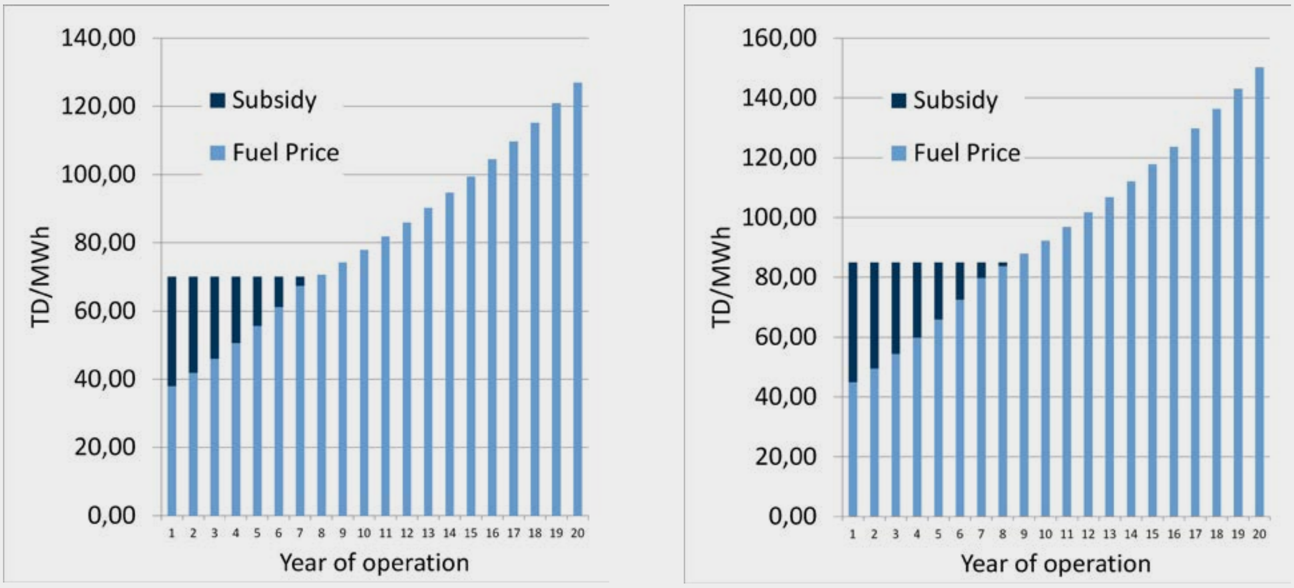
$$\text{Specific Saved Subsidies: } \sum_{i=1}^{n} \left[\frac{\max(P - P_i, 0)}{q^i} * \frac{Y * d^{i-1}}{\eta} \right] \quad in\ \frac{TD}{m^2}$$

Table 87: Energy subsidies for different fuel sources, example IS2

Fuel type	Gas	Heavy Fuel	Unit
Price before subsidy	70	85	TD/MWh
Price after subsidy	38	45	TD/MWh
Increase rate: years 1-6	10%	10%	
Increase rate: years 7-20	5%	5%	
Discount rate	6,75%	6,75%	
Degradation	0,50%	0,50%	
Solar yield	1000	1000	kWh / m²
Boiler efficiency	85%	85%	

The following charts show the development of fuel prices as assumed in the study in case IS2. After the sixth year of adjusting the energy prices for consumers in the tertiary or industrial sector with 10% increase in end consumer prices, energy prices have adjusted themselves to the true, unsubsidized costs of energy for providers (STEG, ETAP). Afterwards, the energy price increase for industrial and tertiary consumers is only 5%/year, which is slightly above inflation level. Subsidies for fuel would no longer be needed to cover the costs between end consumer prices and purchasing costs for Tunisia of conventional fuels.

Figure 74:
Price increase and subsidy development for oil and gas according to assumptions for IS 2, best-case.



Gas savings of TD 125/m²

Heavy fuel savings of TD 163/m² solar collector.

Under current energy price scenario in the example of IS2, the derived gains for the Tunisian state for gas are TD 35 per m² of collector area and for heavy fuel oil TD 41 per m² in the first year after the installation of the solar systems. With the fuel price increase for tertiary and industrial users, the gap between the true costs of unsubsidized fossil fuels and the user price narrows with each year to eventually be phased out in year seven. Higher energy prices for consumers will reduce the deficit resulting from energy subsidies for the Tunisian state budget. These values are applied to the collector area of the respective solar plants. If overall fuel costs for the governmental institutions remain at 2014 levels and consumer prices increase as assumed, the use of solar thermal collectors would save TD 125 per m² of installed collector area if natural gas is replaced and TD 163 per m² if fuel oil is replaced, until fuel subsidies have been replaced in the six-year subsidy phase-out period for this case. Every year the benefit of supporting solar thermal will become less attractive for the government. Therefore, the earlier solar thermal systems are installed, the more benefits can be achieved with the installation, allowing for an economical justification of higher solar subsidies.

Although the conclusion has been drawn from the case IS2, it can also be transferred to the tertiary sector, e.g. to the best-case TS1 (hotel). Gas supply is available in the Sfax region, where irradiation is comparable to Jerba. Since boiler efficiencies are identical for IS2 and TS1 (85%), only the total solar yield is higher for the hotel case (1.3 instead of 1.0), due to lower temperatures level needed; it can therefore be concluded that the substitution of natural gas, under the conditions given, will save fuel subsidies of TD 162.5 per m² of collector area if it substitutes natural gas and if the investment takes place in year one. Subsequently, savings would be less at a later stage if the Tunisian government phases out fuel subsidies as presumed. Since heavy fuel oil is not burned in the hotel sector and the subsidy for LPG was not available, only one value if any can be refered to.

As shown, the overall savings of energy subsidies through the application of solar thermal varies according to each individual case and has to be calculated separately for each case.

In general it can be said that under the conditions presumed in this study, the savings in terms of fuel subsidies for the replacement of oil and gas roughly equal the costs of the investment subsidies paid for solar thermal systems in the industrial sector. In the tertiary sector, solar thermal subsidies are higher than savings in oil and gas subsidies.

Apart from direct savings on fuel subsidies, the use of solar thermal will lead to local investments and value creation, which otherwise might not be the case. Local production and labour opportunities will create taxable income, even though solar thermal systems are exempt from VAT. Though it cannot be specified in this study, it will also create positive macroeconomic benefits.

8.2. Tertiary sector recommendations

The investment in solar thermal is competitive in some tertiary market segments when considering current (2014) subsidy schemes. Tertiary cases competing with liquefied petroleum gas (LPG) are currently a profitable investment option with static payback periods (SPP) of 4.5 to 7 years for hotels, internal rates of return (IRR) 23-18%. When replacing LPG, hospitals, residences and swimming pools also just meet investor expectations (< 5 years SPP) in some regions. Large solar fractions are less profitable, though energy savings of up to 100% are in the best-cases technically feasible. It might therefore be worthwhile to consider higher investment grants for larger systems (higher solar fractions) in order to compensate investors for disadvantages stemming from longer payback periods. This step may be justified, since these grants might be considered beneficial from a macroeconomic perspective.

Calculations clearly show that replacing natural gas is by far not as profitable, with the best-cases being in the hotel sector (SPP of 10 to 14 years, IRR 10 to 5%) and a smaller likelihood of fulfilling the economic expectations of private investors. Policymakers might consider increasing the investment grant slightly for these cases.

According to the study, hotels show the most appropriate demand pattern by far. Other tertiary segments such as hospitals, indoor swimming pools or residences usually have less appropriate demand patterns throughout the year and are more frequently connected to the natural gas grid.

Future market development should thereby focus on:

- **identifying suitable primary impact regions and tertiary actors willing to replace LPFG as fuel with solar thermal,**[65]
- **creating investor confidence by setting up an insurance scheme,**
- **offering planners and investors a simple software tool for easily calculating potential benefits at low costs (e.g. subsidized audits and planning tools),**
- **motivating public actors to consider solar thermal solutions in new buildings (e.g. via solar obligations).**

8.2.1. Identifying primary impact regions and tertiary sector actors in order to exploit most promising market segments (LPG replacement)

The gas transmission network reached 2,240 km in 2012 versus 2,226 km in 2011. The total length of the distribution network increased by 7%, from 11,635 km in

[65] *This includes comprehensive coordination with STEG concerning natural gas grid extension activities.*

2011 to 12,477 km by 2012. STEG has a total of about 644,000 gas customers.

The gas network development programme will be affected by the construction of a large gas pipeline linking the southern transmission pipeline to the north, called "Rocade Ouest", spanning 530 km (diameter 24''). This project will include strengthening the gas transmission capacity and serving more than 170 districts in 2019 (100 districts in 2012).

Some regions on the border with Algeria will be supplied by the Algerian distribution network. An agreement was signed between STEG and SONELGAZ to feed some Tunisian border regions (mainly Kef governorate) via the Algerian gas distribution network.

The following map shows the current gas network and its scheduled extension programme by 2016.

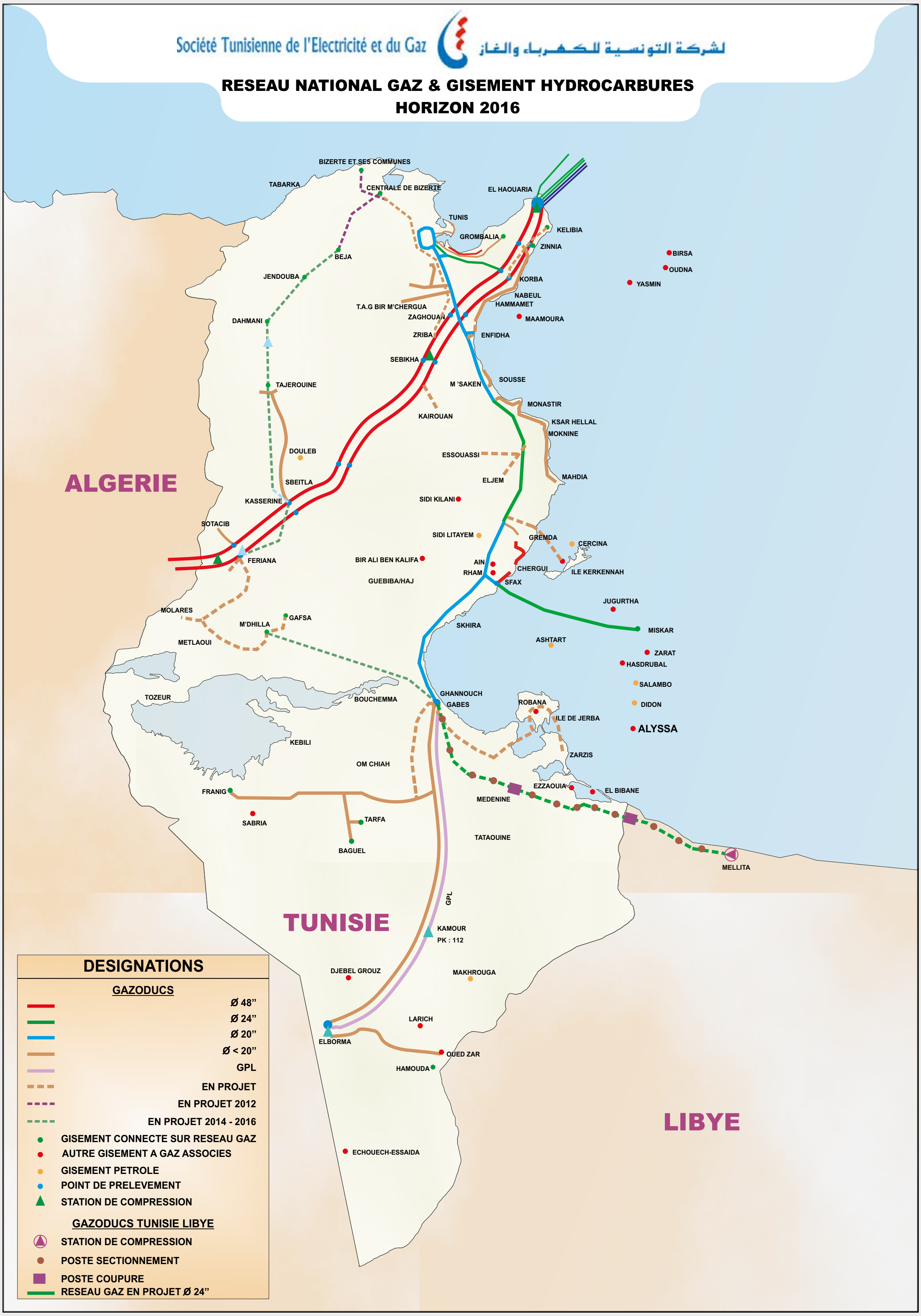
SWH applications in the tertiary sector, including hotels, are economically profitable (with a payback time of about five years) if they replace LPG installations, whereas the profitability for consumers connected to natural gas is harder to achieve.

Some regions like Jerba will soon be supplied with natural gas and thus represent less profitable business cases for SWH applications, especially in the hotel sector.

Other regions like Tabarka, Bizerte, Tozeur and Kebili (in the north and center of Tunisia), which have a strong concentration of hotels, are more likely to represent profitable business cases, since the network expansion programme will not affect them in the near future.

Development agencies as well as solar companies are encouraged to identify and exchange information on the most promising geographical regions in order to promote solar thermal tertiary installations. Since replacing LPG is much more profitable than replacing natural gas, it is highly recommended to follow up on STEG natural gas distribution extension plans. This could be done in collaboration and in continuous exchange with the respective STEG departments in charge of natural gas distribution planning.

Figure 75: STEG Gas grid extension plan 2016



8.2.2. Identify investor target groups interested in profitable mid-term/ long-term investments

In Tunisia, the majority of investors demand static payback periods of five years or less. It has to be noted that demanding SPPs of equal to or less than five years is a very stringent economic requirement for renewable energy systems in general (high initial investment costs, but steady, regularly divided returns over 20 years) and for solar thermal in particular. Often a simple evaluation of the payback period does not represent a comprehensive economic evaluation, as the major share of solar revenues (lifetime 20 years) does not enter the equation. That is why it is also interesting to look at other economic indicators (such as IRR, NPV or comparing LHCs). In addition, it has to be stated that conventional fuel systems have the advantage of low upfront investment (boiler) and continuous operating costs for fuel, but never have full payback. Their advantage consists in binding less cash due to lower investment levels.

Already today, all calculated IRRs for the best tertiary cases are positive and above inflation levels. This means that the investment does not lead to financial losses (also considering the time value of money). However, the calculated NPVs and IRRs have to be set against the context of other investment opportunities (such as expansion/building of additional hotel rooms or other energy efficiency measures) and thus compared to their economic performance.

These types of evaluation will depend on the investor's perspective and his decision to make either long-term or short-term investments. If a longer SPP or DPP would be acceptable, solar thermal systems might become more economically viable all over Tunisia in the tertiary sector (including in those regions which are already connected to the natural gas grid). This development, however, is based on the assumptions (basic requirements for profitability) that

- … the current solar thermal subsidy scheme of 55% investment grant (150 TD/m² ANME; 150 TD/m² UNEP) will persist in the future,

- … energy prices continue to increase (increase rate of 10%/yr for first 5 years and 5%/yr for the following 15 years).

Concerning assumption a), it is realistic that ANME's investment grant of 150 TD/m² remains active in coming years. However, it has to be noted that the additional 150 TD/m² (increasing to 300 TD/m²) currently originate from international funds which might not remain in place forever.

Concerning assumption b), recent drops in oil and gas prices might slow down the political will for subsidy reforms, thus leading to less ambitious energy price scenarios.

Content of the measure:

- potential investor target analysis - Who would accept higher SPPs or DPPs?

- awareness raising events providing information on the profitability of solar thermal systems (including awareness of dynamic economic indicators such as IRR, NPV etc.) as well as visits to demonstration projects

First steps could include:

- presentation of study results to different stakeholder groups via workshops and publications

- description of solar thermal technology with information on planning needs and other requirements,

- visits to existing demonstration plants

Stakeholders:
tertiary sector institutions (public, tourism, health sector, educational sector, military), industry associations, installers, engineers, etc.

Executing bodies:
ANME, industry associations, planning institutes and engineering companies

8.2.3. Create investor confidence with the "new" technology by establishing an affordable insurance scheme to reduce risks involved in ST investment

Goal and description:
Solar thermal systems are well known for their use in residential applications. Limited complexity and low prices as well as good financing options make them an economical investment in this area. For large systems, first movers have to be motivated and reassurances given that systems reliably last for 20 or more years and produce the appropriate amount of heat needed. So far, the long lifetime and system reliability are not reflected in the expectation of the payback period. Investors mistrust promises of longer operation or have doubts regarding the long-term heat demand. Only reassurances of financial compensation for potential losses incurred with system failures will give investors the required confidence to invest in solar thermal technology.

Content of the measure:
A credible insurance scheme could help if it compensates for a possible malfunction of the solar thermal system. Important aspects should include:

- creation of the insurance scheme together with a technical body (university/research institute) with thorough knowledge of the technology and its main failures
- access to insurance for certified/qualified installers at lower rates or exclusively only
- cost credibility through some kind of "government backed guarantee/securities"

First steps could include:

- analysis of common defaults of large ST systems, identification of best practices in large system installation, also considering international examples
- analysis of existing insurances for technical malfunctions
- talks with stakeholders involved in such a scheme and potential clients to identify needs
- set up of a scheme based on current insurance types for technical products/large scale industrial sites and have them evaluated by installers
- evaluation of monitoring schemes for large solar thermal systems together with a nationally accredited research institute

Stakeholders:
insurance companies, installation companies, decision makers in focus sectors

Executing bodies:
ANME, industry associations, installers, insurance companies

8.2.4. Facilitate calculation of individual benefits for stakeholders

Goal and description: Individual energy audits help identify a lack of efficiency. These should include aspects of the appropriateness using alternative energies for heat and electricity generation. A simple simulation instrument might enable energy consultants to make estimates of the energy savings and economic benefits of solar thermal systems and give some basic, standardized information on the specific needs of the technology (e.g. space, tubing, storage). The tool should enable trained energy consultants to give initial assessments to potential clients.

Measures could include:

- programming/adaption of a simple simulation tool to calculate energy yield and economic benefits of solar systems at different geographical sites
- training of energy consultants/engineers in using the tool
- information of the broader public on this service with focus on special target groups

First steps could include:

- definition of input criteria for such tools and standardized information provided to energy consultants and clients
- test runs of the tool with energy experts and potential clients

Stakeholders:
representatives of target groups, energy experts and specilized consultants

Executing bodies:
ANME, software programming company, representatives of solar industry/other renewable industries, energy efficiency agencies

8.2.5. Create non-financial incentives for marketing with a "Green Tourism Label"

More than 70% of hotels in Tunisia are in geographical areas without access to cheap natural gas (Jerba, Tozeur) and therefore provide interesting business cases. The attractiveness of investing in ST could even be increased by using the marketing effect of "environmentally friendly hotels".

Goal and description:
Extra marketing value could be added by the creation of a "Green Tourism Label" as well as a corresponding ranking of hotels. The label should consider categories such as energy efficiency and the use of renewable energies. But other aspects (e.g. waste disposal, water usage, etc.) might also be included in the future. This label should be actively promoted across the country to create competition among hotels to become as "green" as possible. In addition, it could be used for tourism agencies in Tunisia and abroad to position the country as an environmentally-friendly destination in the Mediterranean. Examples and showcases of the "Green Hotels" should be promoted actively in official tourism magazines, trade fairs and websites, thus increasing the marketing effect for all those hotels participating in the scheme.

Measures could include:

- actively using energy audits and efficiency evaluations of hotels (comparable to eco-labelling) and creating a ranking of energy efficient hotels
- using the most effective hotels (ranking) in official national and international marketing campaigns to stimulate competition between hotels to become more energy efficient
- positioning tourism in Tunisia and abroad as one with low carbon footprint
- providing technical/financial support to facilitate energy audits and set up a ranking mechanism for hotels.

First steps could include:

- list hotels with "Solar thermal/PV"-systems and highlight this in official publications/country information including images etc.
- identify criteria for "green labels" and create ranking according to well known mechanisms among consumers/stakeholders (e.g. energy labelling)
- describe guidelines and evaluation criteria for a "green" hotel together with the relevant stakeholder association(s)
- consider a consultative mechanism among stakeholders to have this label accepted among the focus group
- information about internationally available criteria for "eco-audits"

Focus groups:
hotel association, Ministry of Tourism, relevant agencies, hotel chains, hotel owners

Executing bodies:
ANME, marketing agency, representatives of solar industry, energy efficiency agencies[66]

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[66] *So far no exclusive labels referring to solar or energy efficiency exist, but useful references might include http://www.green-tourism.com/ or http://www.organic-network.com/ehc-zertifizierung.html, 27. Jan. 2015*

• Malta (http://www.ecolabelindex.com/ecolabel/eco-certification)
• UK & Ireland (http://www.ecolabelindex.com/ecolabel/green-tourism-business-scheme)
• Italy (http://www.ecolabelindex.com/ecolabel/legambiente-turismo)
• Galapagos (http://www.ecolabelindex.com/ecolabel/calidad-galapagos)
• EU (http://www.slovenia.info/?ps_eu_marjetica=0)

These labels operate on global scale:
• Eco Hotels Certified (http://www.ecolabelindex.com/ecolabel/eco-hotels-certified)
• Green Globe Certification (http://www.ecolabelindex.com/ecolabel/green-globe)
• Green Key (http://www.ecolabelindex.com/ecolabel/green-key)
• Green Key Eco-Rating Programme (http://www.ecolabelindex.com/ecolabel/green-key-hotel-association-of-canada)
• International Eco Certification Programme (http://www.ecolabelindex.com/ecolabel/international-eco-certification-programme)
• Sustainable Tourism Education Programme (http://www.ecolabelindex.com/ecolabel/sustainable-travel-eco-certification-programme)
• David Bellamy Conservation Award (http://www.ecolabelindex.com/ecolabel/david-bellamy-conservation-award)
• EarthCheck (http://www.ecolabelindex.com/ecolabel/earthcheck)

8.2.6. Solar building obligation for public (and private) buildings

Goal and description:
In new buildings, solar thermal systems can be added very cost efficiently when planned and integrated into the system right from the beginning. Building obligations make it compulsory to include specific technologies. While a certain percentage of heat provision with solar energy is often the cheapest option if planned from the start (e.g. 20% for domestic hot water), higher coverage might require additional incentives. Solar building obligations might also be considered for major refurbishments, though exemptions have to be carefully considered since not all buildings will be appropriate for solar thermal systems. It seems to be advisable to start with public buildings, since resistance of pressure groups might be lower.

Measures could include:

- compulsory solar thermal installations to cover a certain percentage of energy consumption (e.g. 20%) with solar thermal (or other renewable technologies), if technically possible (central water heaters) for new buildings
- an initial phase with public buildings, after some years the obligation could cover all new buildings

First steps could include:

- evaluate current building legislation and compliance of compulsory measures with relevant laws
- define cases of application of law as well as exceptions
- use international examples (e.g. Nearly Zero-Energy Buildings Directive 2010/31/EU), energy audits for government owned buildings, German EEWärmeG, project of the "European Solar Thermal Industry Federation" (ESTIF) on best practices[67]

Flanking measures could include:

- control legal compliance since in many countries control lags behind legislation
- establish a fund for refurbishment of government buildings with RES for old buildings
- use tendering processes for large-scale solar thermal systems (or project bundles) to get internationally competitive prices and engineering

Focus groups:
architects, planners, investors

Executing bodies:
ANME, relevant ministries

8.3. Industrial sector recommendations

Solar thermal applications in the industrial sector show a very low level of profitability as they compete with low-priced natural gas or heavy fuel oil for heat generation. Competing with fuel oil is a bit more attractive than competition with natural gas, since it is around 16% more expensive per kWh. However, none of the studied cases come close to economic expectations of industry decision-makers (SPP ≤ 5 years, IRR ≥ 20%), which are particularly high due to short-term investment perspectives and a broad choice of profitable investment alternatives. IRR ranges between 7% and 1% and SPPs between 12 and 30 years for the best-cases analyzed. When applying the new proposed subsidy scheme (FTE) of ANME (combination of grant, credit financing via soft loans and bonus payment), it must be noted that SPP rates do not improve but become worse. DPP and IRR rates, however, show a noticeable leverage and improvement. The subsidy share of the overall investment more than doubles, but profitablility still remains below the defined expectations.

Market development of solar thermal energy in the industry through economically attractive projects would require considerably higher energy price levels and, as a result, would depend on the reduction of fossil energy subsidies. Under current conditions and an assumed energy price increase scenario, projects would need grant support of at least 75%, which only seems realistic in the context of demonstration projects. At 2014 subsidy levels for gas and oil, savings for the state only justify the current grant level of around TD 150/m² of collector

[67] *http://www.erec.org/projects/finalised-projects/k4-res-h/key-issue-3.html, 30 Jan, 2015*

area[68] (10-15% of investment), as can be seen when calculating public benefits involved with the replacement of fuel subsidies with solar thermal (cf. chapter 8.1). Higher grant rates result in extra costs for the public as they surpass current subsidies on fossil fuels. It is therefore unlikely that higher grant rates will be introduced at national level.

Relatively speaking, flat plate collector (FPC) systems operating at low process temperatures (max. ~ 65°C) are the most cost-effective solutions at the moment. However, in order to reach higher process temperature levels and to increase the potential and flexibility of solar process heat integration, other collector technologies have to be considered in the long run.

Until more promising framework conditions for market development are reached, the following measures can be considered:

- supporting solar thermal technology development with highly subsidized demonstration plants via grants

- implementing more cost effective energy saving solutions and renewable energy technologies (energy efficiency, photovoltaics, etc.)

8.3.1. Support of demonstration projects

Goal and description:
Demonstration projects can help to improve the competitiveness of solar process heat technology by triggering learning effects which lead to cost reductions. They also serve as a showcase and reference point for follow-up projects which facilitate market development once favourable conditions are reached.

Current investor expectations of five years static payback period (SPP) or IRR of more than 20% per year are far from being met under the current subsidy scheme. Investors who have these high expectations or who see more profitable alternative investment opportunities will not invest in solar thermal projects. In order to meet these expectations, the grant rate for low-temperature solar thermal systems must reach 75% (IS2) or more of the initial costs. For higher temperature systems, grant rates would have to be increased according to the higher technology costs. Such favourable grant rates cannot be financed on a large scale, but serve mainly to stimulate first movers in order to gain experience and to enable learning effects.

Since conflicting positions arise between the very short ROI expectations of the investors and a limited willingness to pay very high percentage of subsidies of state actors, it might be an option to implement a levy per kWh saved by the solar system after the point of financial amortization, e.g. 50% of the profit. Thus both sides might benefit from energy savings, regardless of future energy price development. However, acceptance among the industry for this approach remains questionable.

At least every two years, market price reviews should examine the cost developments of each technology to consider the effect of a learning curve in technology development and planning.

Based on the evaluation of the study, financial aspects and profitability should be discussed with proactive companies, also taking into consideration non-monetary aspects such as corporate social responsibility and discussions with international donor banks/institutions which are willing to support suitable grants.

Flanking measures:

- soft loans at around inflation rate might support the willingness to invest; however, the effect on profitability is limited as was shown in the analysis of the proposed ANME FTE subsidy scheme. Soft loans can improve the profitability of a project by some percentage and should be supplemented with a grace period of several years to develop their full potential but require investors with long term investment goals.

- visits to pilot plants with relevant industry decision makers should be organized.

Focus groups:
industrial companies, industry associations

Executing bodies:
ANME, solar companies, certain industry associations

[68] *Or, to be precise, TD 125/m² collector area for natural gas replacement and TD 163/m² for fuel oil replacement*

8.3.2. Implementation of more cost-efficient energy saving options (energy efficiency/alternative renewables)

Energy audits of Tunisian companies have shown that the energy consumption of companies is still not state-of-the-art compared to international levels, and that thermal energy efficiency measures like the use of waste heat, etc. offer a large potential for cost effective energy savings that is more favourable than for solar thermal. Support for energy efficiency might thus be the most cost-effective solution for state and industry to reduce energy consumption and emissions in the sector.

Alternative energy production sources such as photovoltaics might also be considered to reduce the overall energy costs on the electricity side.

Measures could include:

- review existing energy audits and audit methodologies
- identify barriers for energy efficiency measures
- list cost-effective energy saving technologies for the industry based on international experience and best practices (benchmarking)
- support a framework for energy service companies

Focus groups:
industrial companies, industry associations

Executing bodies:
ANME, associations of certain industries

8.3.3. Further recommendations for the industrial sector

The creation of an insurance scheme for solar thermal installations for industrial users (like for the tertiary sector) can also be applied.

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10. Appendix

10.1. A: Economic calculation formulas and abbreviations

List of terms and abbreviations used:

Period under Consideration: Lifespan of solar plant in years, usually at least 20 years	
Fuel Price in TD/MWh = Millimes/kWh	
Energy price increase rate: Constant for the first six years. From the seventh year it is five percent less. Standard value is 10%/5%. Other values only used for sensitivity analysis (both values are incremented by the same amount)	
Collector Price: TD per m² collector area	
Subsidy Rate: in TD per m² collector area	
Solar Savings: Solar energy savings * fuel price	
Present Value – PV: the value of an expected income stream determined as of the date of valuation.	$PV = \frac{C_T}{(1+r)^n}$ C_1 = Cash Flow at Period 1 r = Rate of Return n = Number of Periods
Net Present Value – NPV: the sum of the present values (PVs) of incoming and outgoing cash flows over a period of time.	$NPV = -C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \dots\dots + \frac{C_T}{(1+r)^T}$ $-C_0$ = Initial Investment C = Cash Flow r = Discount Rate T = Time
Levelized Heat Costs – LHC: Annuity of all costs/solar yield in TD/MWh Levelized Cost of Energy (LCOE, also called levelised energy cost or LEC), is a cost of generating energy (usually electricity) for a particular system. It is an economic assessment of the cost of the energy-generating system including all the costs over its lifetime: initial investment, operations and maintenance, cost of fuel, cost of capital. A net present value calculation is performed and solved in such a way that for the value of the LCOE chosen, the project's net present value becomes zero. This means that the LCOE is the minimum price at which energy must be sold for an energy project to break even.[69]	

[69] *Compare: http://www.nrel.gov/analysis/tech_lcoe_documentation.html , 15 April 2015*

Interest on Capital – IoC	$A = P(1 + \frac{r}{n})^{nt}$ A = Amount accumulated P = principal r = interest rate n = compoundings per period t = number of periods

Internal Rate of Return – IRR: Adapted IoC so that NPV = 0

The internal rate of return on an investment or project is the "annualized effective compounded return rate" or rate of return that makes the net present value (NPV as NET*1/(1+IRR)^year) of all cash flows (both positive and negative) from a particular investment equal to zero. It can also be defined as the discount rate at which the present value of all future cash flow is equal to the initial investment or, in other words, the rate at which an investment breaks even.

In more specific terms, the IRR of an investment is the discount rate at which the net present value of costs (negative cash flows) of the investment equals the net present value of the benefits (positive cash flows) of the investment.[70]

Dynamic Payback Period – DPP: Adapted period under consideration so that NPV = 0

A capital budgeting procedure used to determine the profitability of a project. In contrast to an NPV analysis, which provides the overall value of a project, a discounted or dynamic payback period provides the number of years it takes to break even after undertaking the initial expenditure. Future cash flows considered are discounted to time "zero." This procedure is similar to a payback period; however, the payback period only measures how long it takes for the initial cash outflow to be paid back, ignoring the time value of money.[71]

Static Payback Period – SPP: Adapted period under consideration so that IoC = 0

Payback period in capital budgeting refers to the period of time required to recoup the funds expended in an investment, or to reach the break-even point. For example, a TD 1000 investment which returned TD 500 per year would have a two-year payback period. The time value of money is not taken into account. Payback period intuitively measures how long something takes to "pay for itself." All else being equal, shorter payback periods are preferable to longer payback periods.[72]

10.2. Appendix B: Technology costs, economic boundary assumptions

Table 88: Collector price assumptions

Collector area-specific system costs Technology	Plant size/m²	Spec. price/ (TD/m²)
Flat plate (incl. import tax ≥ 1000 m²)	100	1000
	1000	840
	5000	630
Vacuum tube (incl. import tax)	100	1365
	1000	1050
	5000	787,5
Concentrating	500	1924
	2000	1082
	10000	902

Table 89: Tank price assumptions

Specific tank costs tank type	Costs/ TD per litre
DHW (glazed), incl. import tax	2,81
Buffer tank	1,48
Buffer tank (high pressure), incl. import tax	2,96

Table 90: Operation & maintenance cost assumption

Operation and maintenance costs (O&M) System type	% cost of total system costs/ per year
Non-concentrated	1%
Concentrated	2%

[70] *http://en.wikipedia.org/wiki/Internal_rate_of_return, 15 April 2015*

[71] *Compare: http://www.investopedia.com/terms/d/discounted-payback-period.asp, 15 April 2015*

[72] *http://en.wikipedia.org/wiki/Payback_period, 15 April 2015*

Table 91: Collector degradation assumption

Degradation of solar thermal system	% of efficiency loss per year
All systems	0,5%

Table 93: System lifetime assumption

Lifetime (period under consideration)	Years
All systems	20

10.3. Appendix C: Economic boundary conditions

Table 92: System subsidy assumptions

Investment subsidy + subsidy rate: Application type	Total in TD/m² collector area Subsidy rate: (m² collector area* subsidy)/ total investment
Tertiary systems	300
Industrial systems	150

Table 94: Interest on Capital employed assumptions

Interest on capital employed Application type	
Tertiary systems	6%
Industrial systems	8%

Table 95: Fuel price assumptions

Energy-specific fuel price (TD/kWh) Energy/source	Gross price (TD/ kWh)	Energy content		Information source
Natural gas	0,038	10,42	kWh/m³	STEG (May 2014)
Liquid petroleum gas	0,086	12860,568	kWh/ton	Ministère de l'industrie et de la technologie (2014)
Domestic fuel oil	0,125	10	kWh/l	
Heavy fuel oil	0,045	11383,812	KWh/ton	Ministère de l'industrie et de la technologie (2014)
Electricity (low voltage)	0,3481	1	kWh	STEG (May 2014)
Electricity (medium voltage)	0,19706	1	kWh	STEG (May 2014)

Table 96: Energy price increase assumptions

Increase rate for energy costs	%
Years 1-6	10%
Years 7-20	5%

Table 97: Inflation assumptions

Inflation rate 2015 - 2034	%
Per year	4,3%

Table 98: Solar irradiation assumptions

Solar irradiation	Tunis	Sfax	Jerba
Global horizontal/ kWh/m²	1800	1992 (+11%)	
Direct horizontal/ kWh/m²	1090	1286 (+18%)	

10.4. Appendix D: Tertiary cases

10.4.1. TS1 – Domestic hot water for hotels

10.4.1.1. Location: Jerba; fuel: LPG; collector type: FPC

Figure 76:
Sensitivity analysis between collector area and storage tank size to determine solar efficiency for flat plate collectors (FPC), hotel case (TS1)

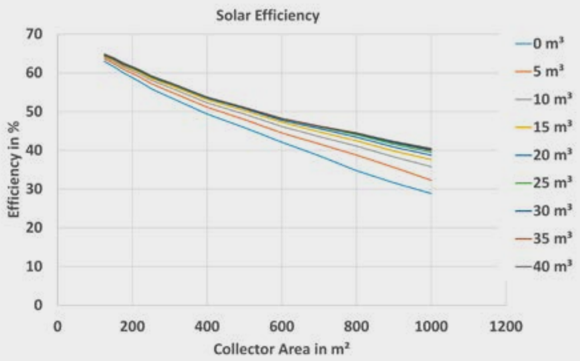


Figure 77:
Sensitivity analysis between collector area and storage tank size to determine solar fraction for flat plate collectors (FPC), hotel case (TS1)

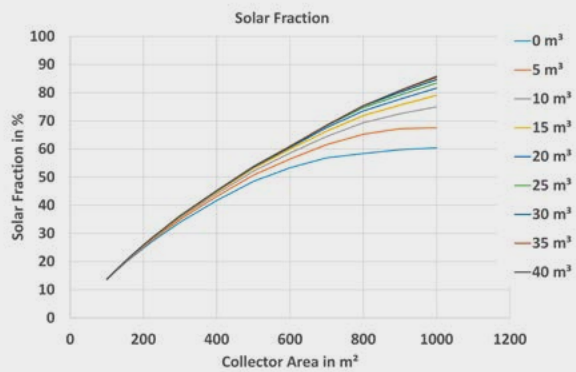


Figure 78:
Sensitivity analysis between collector area and storage tank size to determine solar energy savings for flat plate collectors (FPC), hotel case (TS1)

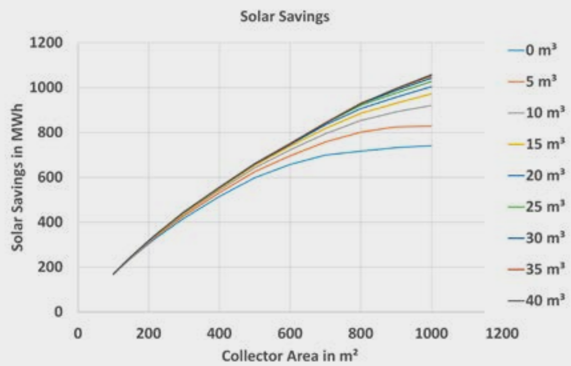


Table 99: Maximum net present value depending on solar thermal system size and storage capacity system, flat plate collectors (FPC), hotel case (TS1)

NPV [TD*1000]	100 m²	250 m²	275 m²	300 m²	400 m²	500 m²	600 m²	700 m²	800 m²	900 m²	1000 m²
0 m³	210	437	468	498	596	674	713	725	697	672	636
5 m³	196	436	469	501	609	707	765	814	833	821	776
10 m³	181	429	465	499	612	721	796	863	910	924	925
15 m³	165	419	456	491	609	723	810	889	950	976	1001
20 m³	150	406	443	480	599	716	805	900	972	1008	1042
25 m³	134	391	429	466	587	705	797	897	981	1025	1066
30 m³	119	376	414	451	572	690	783	885	977	1030	1077
35 m³	103	361	398	435	556	673	766	869	965	1026	1079
40 m³	87	345	382	419	539	655	746	848	945	1013	1072
Maximum	210	437	469	501	612	723	810	900	981	1030	1079

Table 100: Economic evaluation of best economic cases depending on system size and storage volume

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
100	0	1463	54,2	209.973	26,3	5,2	4,5
200	0	1340	57,8	373.746	24,9	5,5	4,7
300	5	1258	63,9	500.850	22,7	6,1	5,2
400	10	1193	67,9	612.139	21,4	6,5	5,4
500	15	1150	70,1	723.184	20,8	6,7	5,6
600	15	1084	71,3	809.865	20,5	6,8	5,6
700	20	1048	73,0	900.439	20,1	6,9	5,8
800	25	1013	74,5	980.816	19,7	7,1	5,9
900	30	966	76,8	1.029.723	19,1	7,3	6,0
1000	35	926	78,6	1.079.353	18,7	7,4	6,1

Figure 79:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), hotel case (TS1)

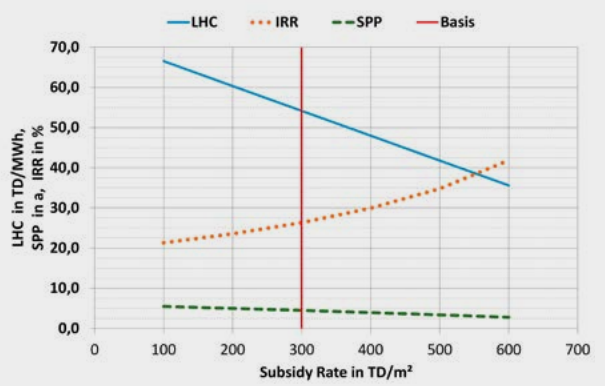
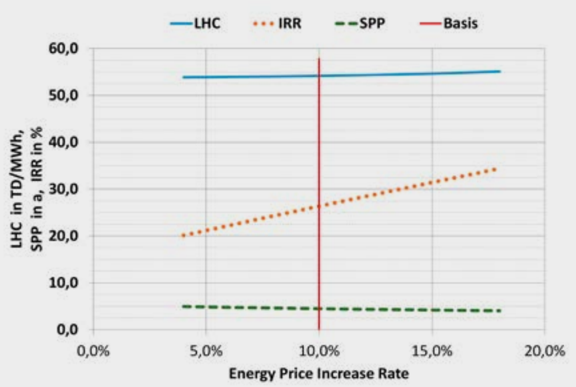


Figure 80:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), hotel case (TS1)

Figure 81:
Sensitivity analysis of relative fuel price changes (%) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), hotel case (TS1)



10.4.1.2. Location: Jerba, fuel: LPG, collector type: CPC

Figure 82:
Sensitivity analysis between collector area and storage tank size to determine system efficiency for vacuum tube collectors (CPC), hotel case (TS1)

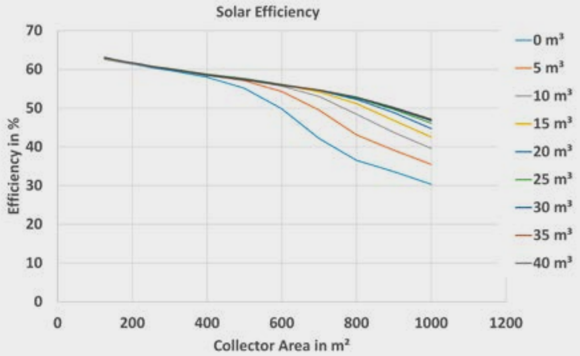


Figure 83:
Sensitivity analysis between collector area and storage tank size to determine the solar fraction for vacuum tube collectors (CPC), hotel case (TS1)

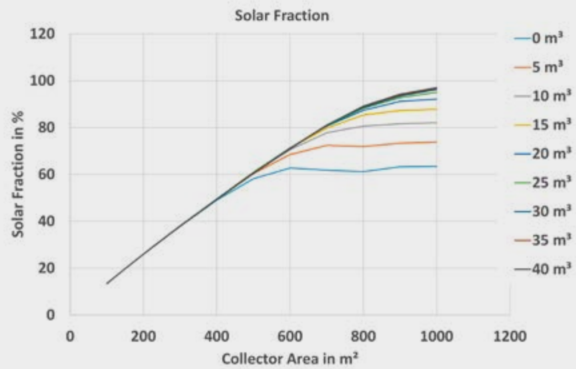


Figure 84:
Sensitivity analysis between collector area and storage tank size to determine energy savings through solar for vacuum tube collectors (CPC), hotel case (TS1)

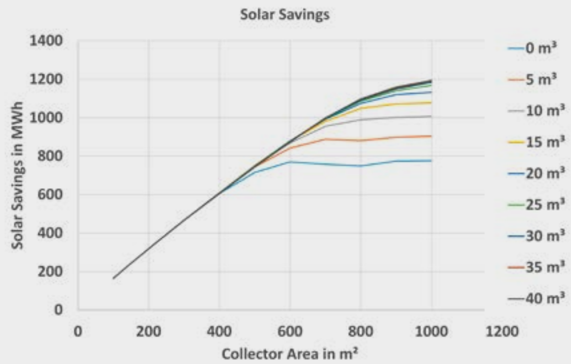


Table 101: Maximum net present value depending on solar thermal system size and storage capacity system, vacuum tube collectors (CPC), hotel case (TS1)

NPV [TD*1000]	100 m²	200 m²	300 m²	400 m²	500 m²	600 m²	700 m²	800 m²	900 m²	1000 m²
0 m³	163	317	467	612	711	720	617	528	509	455
5 m³	147	302	453	603	746	832	833	747	714	667
10 m³	131	287	438	587	743	863	938	925	882	834
15 m³	115	271	422	570	727	863	967	1015	991	945
20 m³	99	254	405	552	707	850	970	1044	1062	1027
25 m³	83	238	388	534	687	832	962	1047	1081	1074
30 m³	67	222	371	516	667	811	950	1043	1081	1086
35 m³	51	206	354	498	648	792	934	1034	1076	1082
40 m³	36	189	337	480	629	772	916	1021	1066	1072
Maximum	163	317	467	612	746	863	970	1047	1081	1086

Table 102: Economic evaluation of best economic cases depending on system size and storage volume

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/ m²]	LHC [TD /MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
100	0	1440	81,7	162.686	17,7	7,9	6,4
200	0	1398	81,5	316.553	17,8	7,9	6,4
300	0	1365	80,8	467.131	18,0	7,8	6,3
400	0	1332	80,1	611.876	18,1	7,7	6,3
500	5	1309	80,9	745.693	18,0	7,8	6,3
600	15	1287	82,9	863.161	17,5	8,0	6,5
700	20	1247	83,4	970.080	17,4	8,0	6,5
800	25	1193	84,8	1.046.991	17,2	8,1	6,6
900	30	1124	87,3	1.081.486	16,7	8,4	6,7
1000	30	1042	89,7	1.086.210	16,3	8,6	6,9

Figure 85:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Jerba area with vacuum tube collectors (CPC), hotel case (TS1)

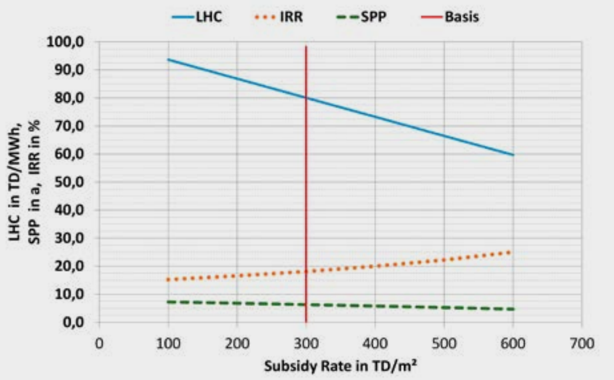
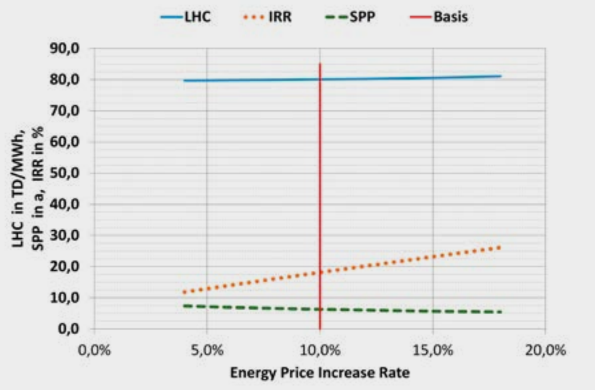


Figure 86:
Sensitivity analysis of fuel price effects (TD/ MWh) on LHC, IRR, SPP, Jerba area with vacuum tube collectors (CPC), hotel case (TS1)

Figure 87:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Jerba area with vacuum tube collectors (CPC), hotel case (TS1)



10.4.1.3. Location: Tunis, energy: NG, collector type: FPC

Figure 88:
Sensitivity analysis comparing collector area and storage tank size to determine system efficiency for flat plate collectors (FPC), hotel case (TS1)

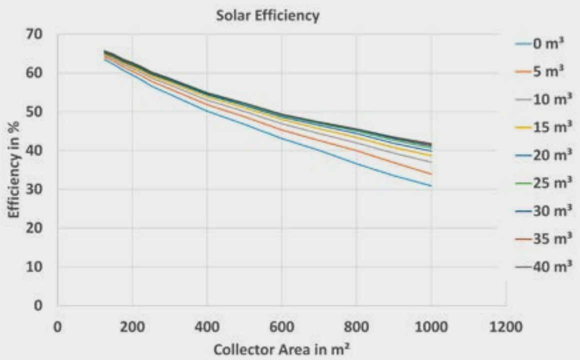


Figure 89:
Sensitivity analysis comparing collector area and storage tank size to determine the solar fraction for flat plate collectors (FPC), hotel case (TS1)

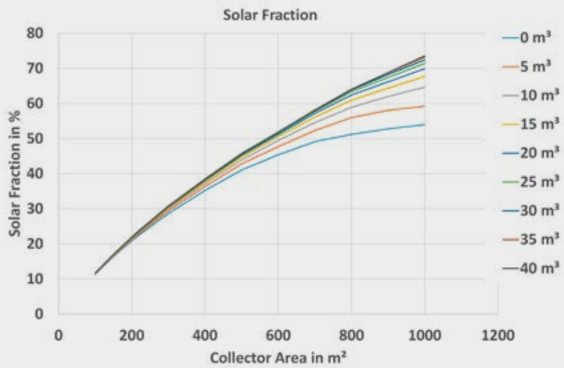


Figure 90:
Sensitivity analysis between collector area and storage tank size to determine solar energy savings for flat plate collectors (FPC), hotel case (TS1)

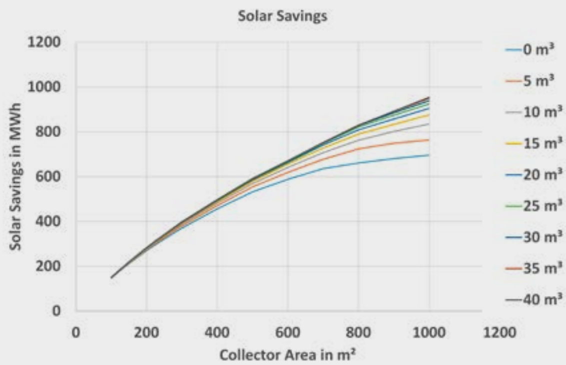


Table 103: Maximum net present value depending on solar thermal system size and storage capacity system, flat plate collectors (FPC), hotel case (TS1)

NPV [TD*1000]	100 m²	300 m²	400 m²	500 m²	600 m²	700 m²	800 m²	900 m²	1000 m²
0 m³	28	43	35	25	2	-24	-62	-101	-139
5 m³	13	34	30	26	10	-7	-29	-63	-102
10 m³	-3	23	22	21	11	0	-14	-38	-62
15 m³	-19	10	11	12	6	0	-9	-29	-46
20 m³	-35	-4	-2	1	-5	-5	-10	-27	-40
25 m³	-51	-19	-16	-12	-17	-16	-17	-30	-40
30 m³	-67	-34	-31	-27	-31	-30	-28	-38	-46
35 m³	-83	-50	-47	-43	-47	-45	-43	-49	-54
40 m³	-99	-66	-63	-59	-64	-62	-60	-65	-66
Maximum	28	43	35	26	11	0	-9	-27	-40

Table 104: Economic evaluation of best economic cases depending on system size and storage volume

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD /MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
100	0	1291	61,4	28.409	9,7	14,0	9,9
200	0	1185	65,3	42.023	8,9	15,1	10,5
300	0	1087	69,5	42.664	8,0	16,3	11,1
400	0	1004	73,4	35.385	7,3	17,4	11,6
500	5	976	76,6	25.661	6,8	18,5	12,1
600	10	940	79,6	11.002	6,3	19,4	12,5
700	15	915	81,3	360	6,0	20,0	12,7
800	15	869	82,6	-9.414	5,8	20,4	12,9
900	20	838	84,6	-26.869	5,5	21,1	13,2
1000	20	796	85,9	-39.774	5,3	21,6	13,4

Figure 91:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), hotel case (TS1)

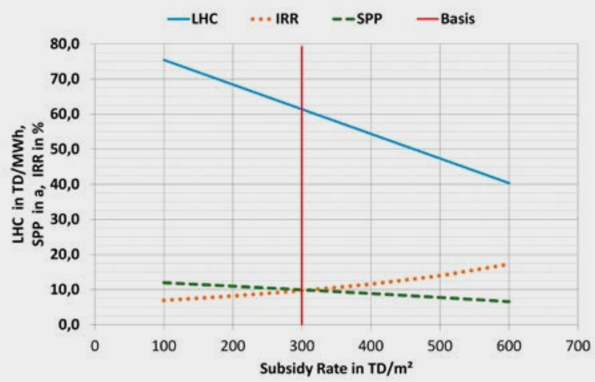


Figure 93:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), hotel case (TS1)

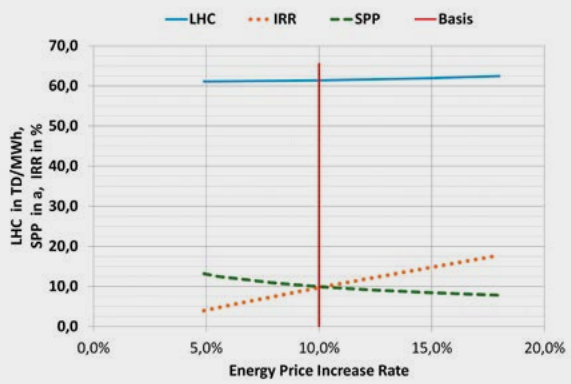
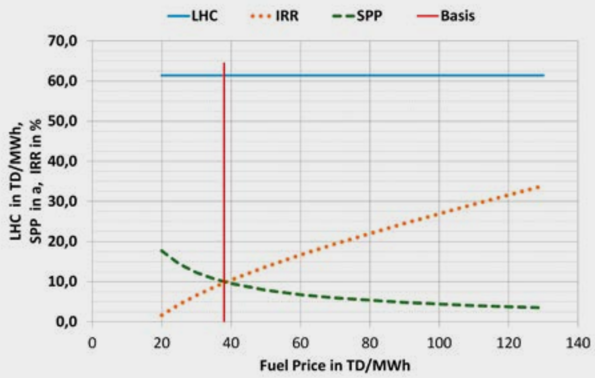


Figure 92:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), hotel case (TS1)



10.4.2. TS 2 – Domestic hot water and space heating for hospitals

10.4.2.1. Location: Tunis; energy: natural gas collector type: FPC

Figure 94:
Sensitivity analysis between collector area and storage tank size to determine system efficiency for flat plate collectors (FPC), hospital case (TS2)

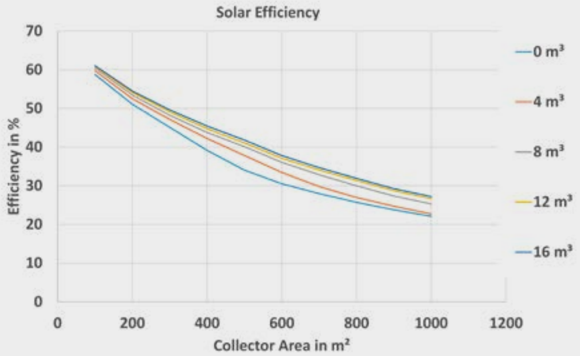


Figure 95:
Sensitivity analysis between collector area and storage tank size to determine solar fraction for flat plate collectors (FPC), hospital case (TS2)

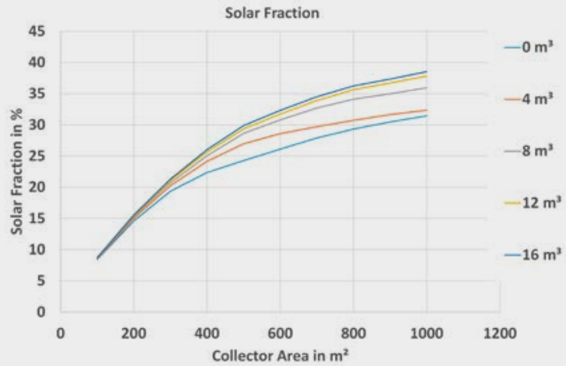


Figure 96:
Sensitivity analysis between collector area and storage tank size to determine solar energy savings for flat plate collectors (FPC), hospital case (TS2)

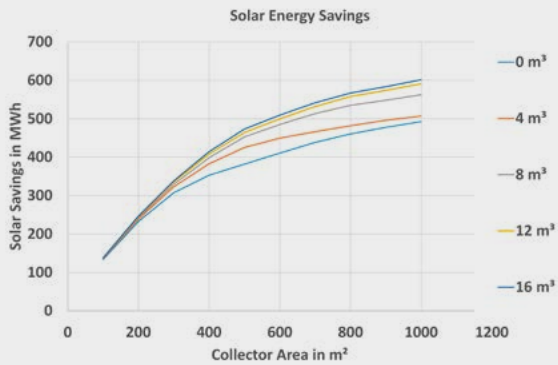


Table 105: Maximum net present value depending on solar thermal system size and storage capacity system, flat plate collectors (FPC), hospital case (TS2)

NPV [TD*1000]	100 m²	200 m²	300 m²	400 m²	500 m²	600 m²	700 m²	800 m²	900 m²	1000 m²
0 m³	12	7	-13	-52	-100	-144	-185	-226	-267	-305
4 m³	0	-2	-14	-42	-79	-127	-176	-222	-265	-307
8 m³	-12	-11	-22	-42	-70	-112	-152	-193	-237	-276
12 m³	-24	-22	-30	-48	-74	-113	-150	-188	-230	-267
16 m³	-37	-34	-41	-56	-80	-119	-156	-194	-235	-271
Maximum	12	7	-13	-42	-70	-112	-150	-188	-230	-267

Table 106: Economic evaluation of best economic cases depending on system size and storage volume

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/ m²]	LHC [TD /MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
100	0	1175	72,4	11.603	7,5	17,2	11,5
200	0	1024	78,3	6.812	6,5	19,0	12,3
300	0	903	85,7	-13.144	5,4	21,5	13,4
400	4	843	92,5	-41.695	4,4	24,0	14,3
500	8	797	97,3	-70.368	3,8	25,8	15,0
600	8	711	105,0	-111.807	2,9	29,1	16,1
700	12	669	110,4	-150.455	2,2	31,5	16,8
800	12	614	116,1	-188.364	1,6	34,3	17,6
900	12	561	122,5	-229.915	1,0	37,8	18,6
1000	12	520	127,8	-266.827	0,4	41,0	19,3

Figure 97:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), hospital case (TS2)

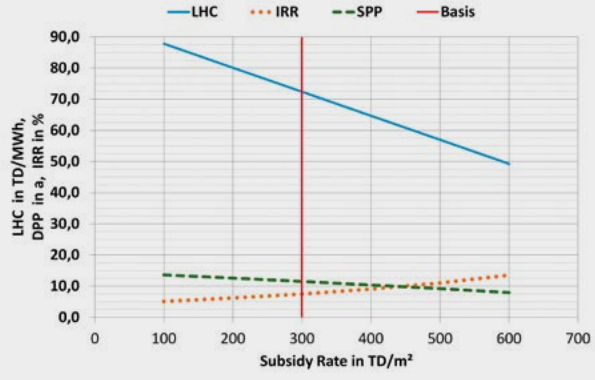


Figure 99:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), hospital case (TS2)

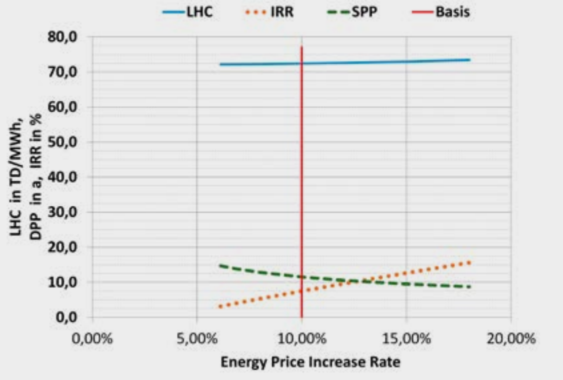


Figure 98:
Sensitivity analysis of fuel price effects (TD/ MWh) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), hospital case (TS2)

10.4.2.2. Location: Jerba, fuel: LPG, collector type: FPC

Table 107: Economic evaluation of one economic case depending on system size and storage volume, hospital case (TS2)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
100	0	1345	63,2	179.565	22,8	6,1	5,1

Figure 100:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Jerba area with flat plate collectors (FPC), hospital case (TS2)

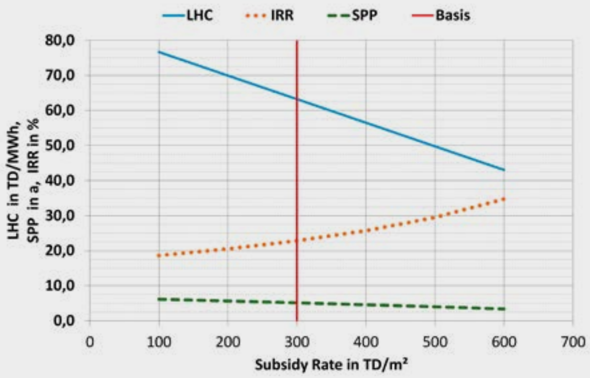


Figure 101:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Jerba area with flat plate collectors (FPC), hospital case (TS2)

Figure 102:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Jerba area with flat plate collectors (FPC), hospital case (TS2)

10.4.2.3. Location: Tunis, fuel: natural gas, collector type: FPC, DHW only

Table 108: Economic evaluation of one economic case depending on system size and storage volume

Collector aea [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD /MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
100	0	1130	70,0	14.102	7,9	16,4	11,2

Figure 103:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), hospital case (TS2)

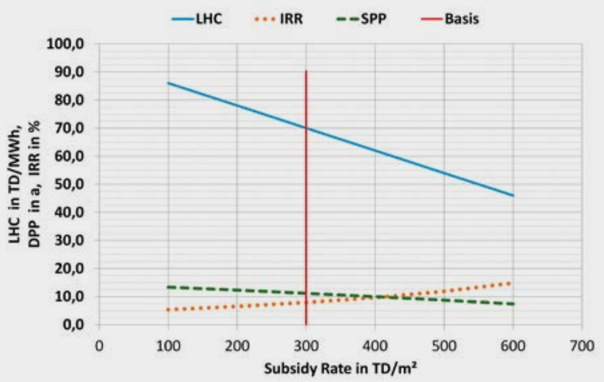


Figure 104:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), hospital case (TS2)

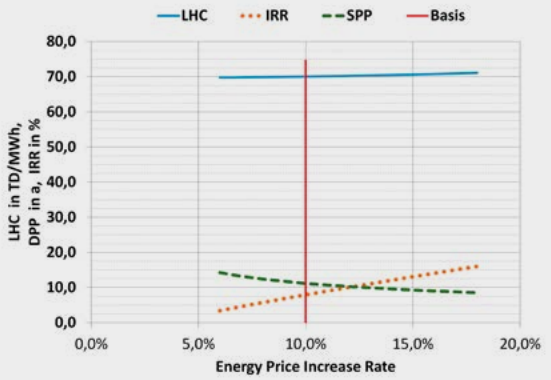


Figure 105:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), hospital case (TS2)

10.4.3. TS3 – Indoor pool, Tunis

10.4.3.1. Location: Tunis, energy: natural gas, collector type: FPC

Figure 106:
Efficiency as a function of the collector area for flat plate collectors (FPC), indoor pool case (TS3)

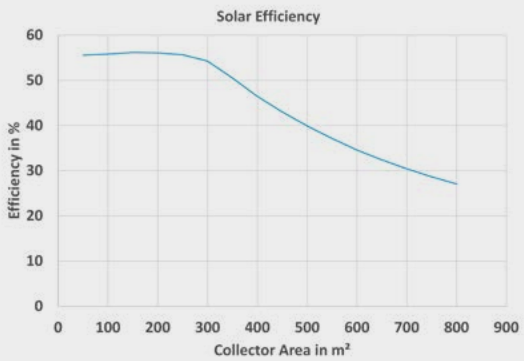


Figure 107:
Solar fraction as a function of the collector area for flat plate collectors (FPC), indoor pool case (TS3)

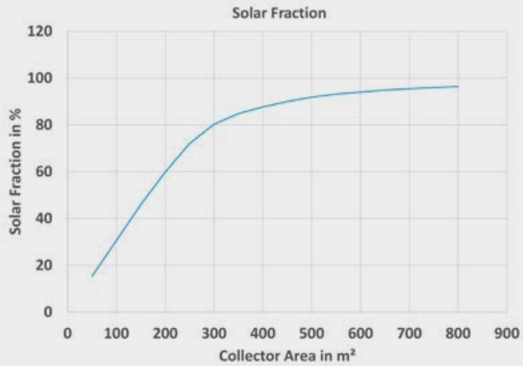


Figure 108:
Solar savings in MWh as a function of the collector area for flat plate collectors (FPC), indoor pool case (TS3)

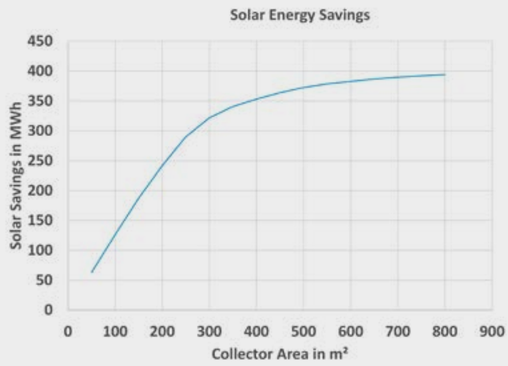


Table 109: Economic evaluation of best economic cases depending on system size and storage volume

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
50	0	1111	71,3	6.170	7,7	16,8	11,3
100	0	1111	71,2	12.381	7,7	16,8	11,3
150	0	1100	71,1	18.660	7,7	16,8	11,3
200	0	1064	72,7	20.383	7,5	17,2	11,5
250	0	1021	74,8	18.476	7,1	17,9	11,8
300	0	944	79,9	4.581	6,2	19,5	12,5
400	0	777	94,7	-45.749	4,1	24,8	14,6
500	0	655,6	109,3	-101298,0	2,4	31,0	16,7
600	0	561	124,4	-160.120	0,8	38,8	18,8
700	0	490	138,6	-217.078	0,0	48,0	20,9
800	0	434	152,3	-271.971	0,0	59,4	22,9

Figure 109:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), indoor pool case (TS3)

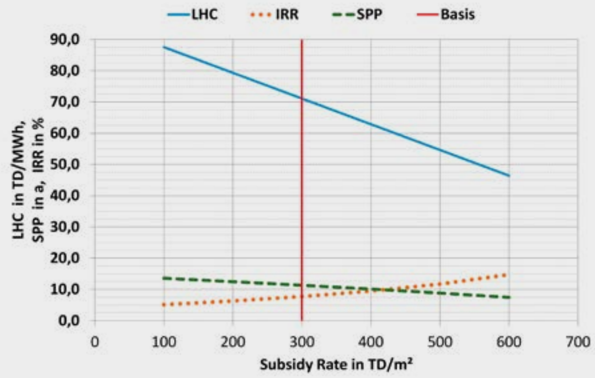
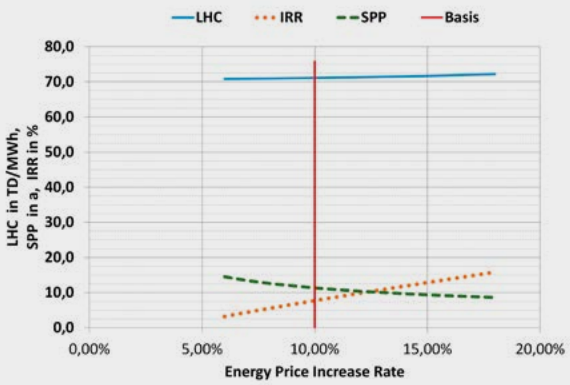


Figure 110:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), indoor pool case (TS3)

Figure 111:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), indoor pool case (TS3)



10.4.4. TS 3 – Indoor pool, Jerba

10.4.4.1. Location: Jerba, energy: LPG, collector type: FPC

Figure 112:
Efficiency as a function of the collector area for flat plate collectors (FPC), indoor pool case (TS3), Jerba

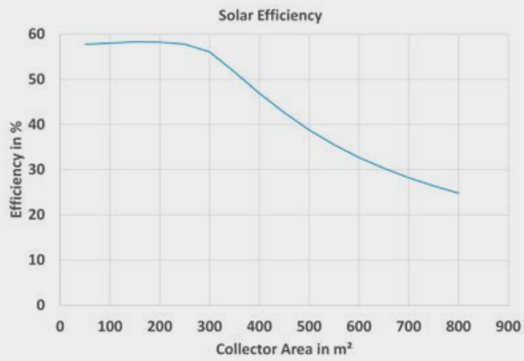


Figure 113:
Solar fraction as a function of the collector area for flat plate collectors (FPC), indoor pool case (TS3), Jerba

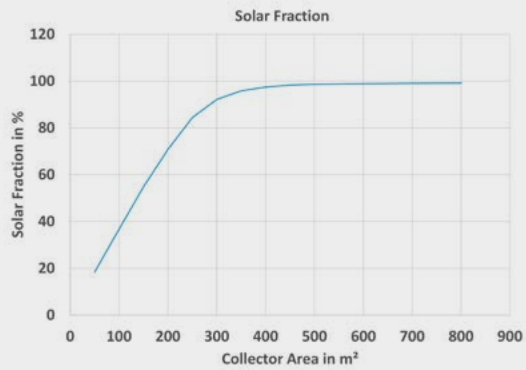


Figure 114:
Solar savings in MWh as a function of the collector area for flat plate collectors (FPC), indoor pool case (TS3), Jerba

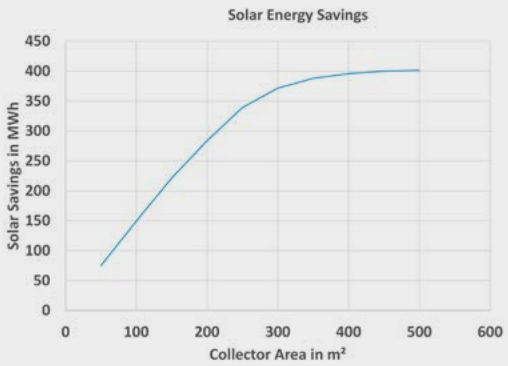


Table 110: Economic evaluation of best economic cases depending on system size and storage volume, Jerba, indoor pool case (TS3)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/ m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
50	0	1320	60,0	90.436	24,0	5,7	4,9
100	0	1317	60,1	180.311	24,0	5,8	4,9
150	0	1299	60,2	266.452	23,9	5,8	4,9
200	0	1249	61,9	337.285	23,4	5,9	5,0
250	0	1194	63,9	396.159	22,7	6,1	5,1
300	0	1090	69,2	414.848	21,1	6,6	5,5
400	0	871	84,4	383.362	17,4	8,0	6,5
500	0	706,7	101,4	322628,0	14,4	9,7	7,6
600	0	591	118,1	258.216	12,1	11,5	8,6
700	0	508	133,8	197.087	10,3	13,3	9,6
800	0	445	148,6	139.318	8,8	15,1	10,5

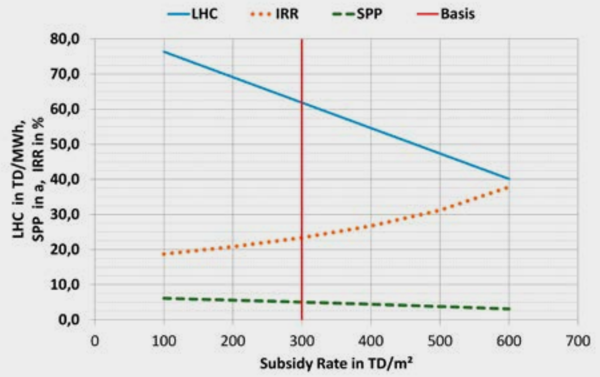


Figure 115:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Jerba area with flat plate collectors (FPC), indoor pool case (TS3)

Figure 116:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Jerba with flat plate collectors (FPC), indoor pool case (TS3)

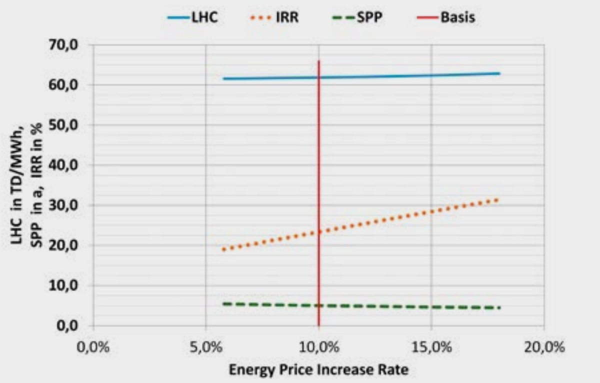


Figure 117:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Jerba area with flat plate collectors (FPC), indoor pool case (TS3)

10.4.5. TS4 – Domestic hot water for the residencies

10.4.5.1. Location: Tunis, fuel: natural gas, collector type: FPC

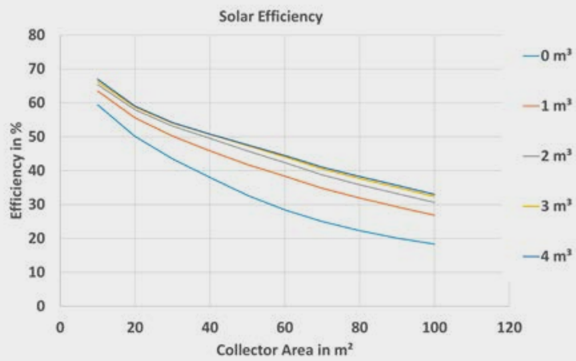


Figure 118:
Sensitivity analysis between collector area and storage tank size to determine system efficiency for flat plate collectors (FPC), residential case (TS4)

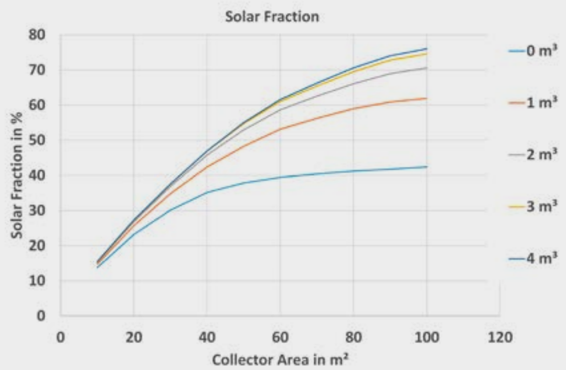


Figure 119:
Sensitivity analysis between collector area and storage tank size to determine solar fraction for flat plate collectors (FPC), residential case (TS4), Tunis

Figure 120:
Sensitivity analysis between collector area and storage tank size to determine solar energy savings for flat plate collectors (FPC), residential case (TS4), Tunis

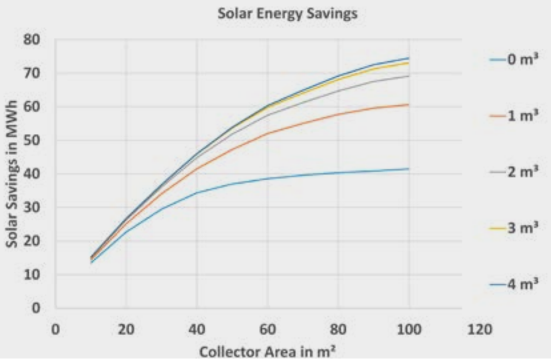


Table 111: Economic evaluation of best economic cases depending on system size and storage volume, Tunis

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
10	0	1188	67,4	1.822	8,5	15,6	10,8
20	1	1108	85,7	-1.063	5,4	21,5	13,3
30	2	1059	94,3	-4.546	4,2	24,6	14,5
40	2	987	96,2	-6.485	3,9	25,4	14,8
50	2	913	100,8	-9.801	3,4	27,2	15,5
60	3	877	108,2	-15.641	2,5	30,4	16,5
70	3	806	115,2	-21.108	1,8	33,7	17,5
80	3	749	121,8	-26.780	1,1	37,2	18,4
100	3	643	138,4	-40.556	0,0	47,5	20,7

Figure 121:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), residential case (TS4)

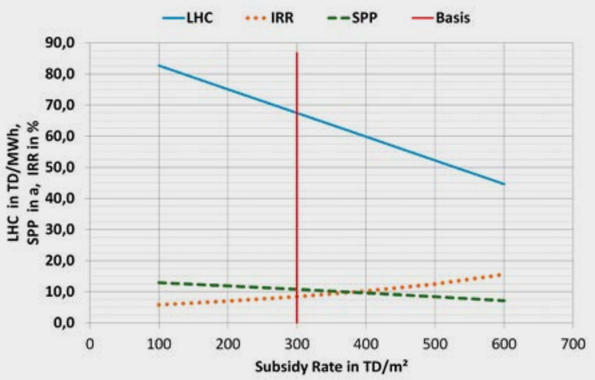
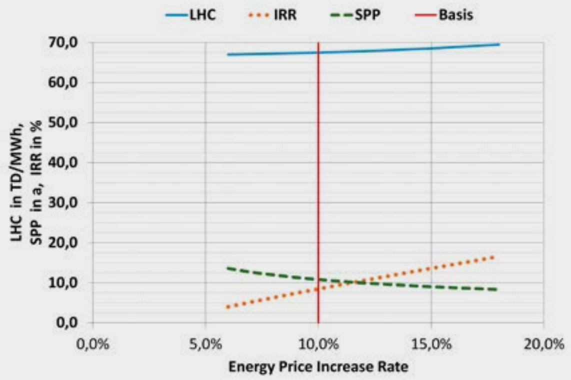


Figure 122:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), residential case (TS4)

Figure 123:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), residential case (TS4)



Location: Jerba, fuel: LPG, collector type: FPC

Figure 124:
Sensitivity analysis of relative changes of subsidy rate on LHC, IRR, SPP, Jerba with flat plate collectors (FPC), residential case (TS4)

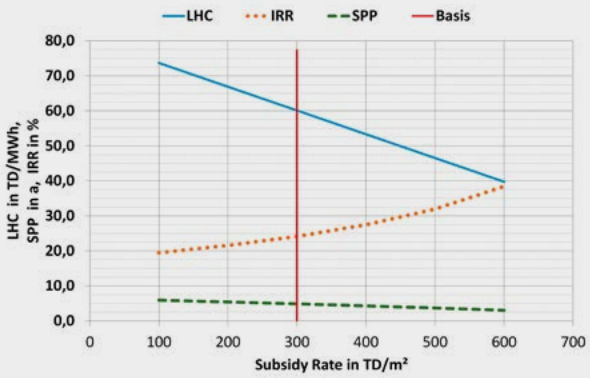


Table 112: Best-case, Jerba with flat plate collectors (FPC), residential case (TS4)

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
10	0	1333	60,1	18.256	24,2	5,7	4,9

Figure 125:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Jerba area with flat plate collectors (FPC), residential case (TS4)

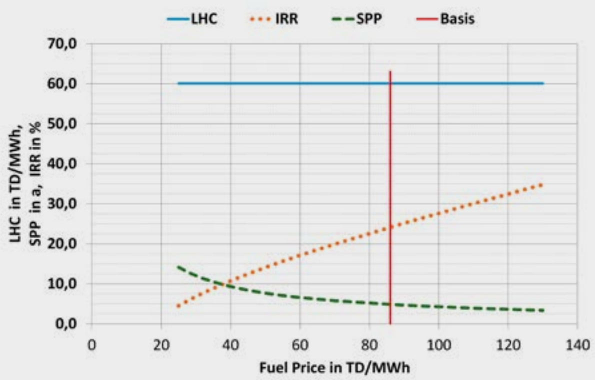
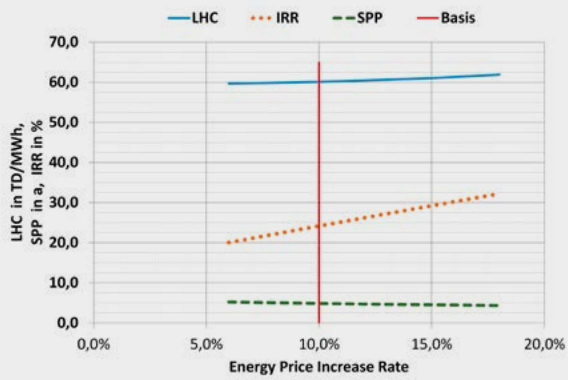


Figure 126:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Jerba area with flat plate collectors (FPC), residential case (TS4)



10.5. Appendix E: Industrial cases

10.5.1. IS1 – Food industry, dairy industry

10.5.1.1. Location: Sfax, Collector type: CPC

Figure 127:
Sensitivity analysis between collector area and storage tank size to determine system efficiency for vacuum tube collectors (CPC), industrial case (IS1), Sfax

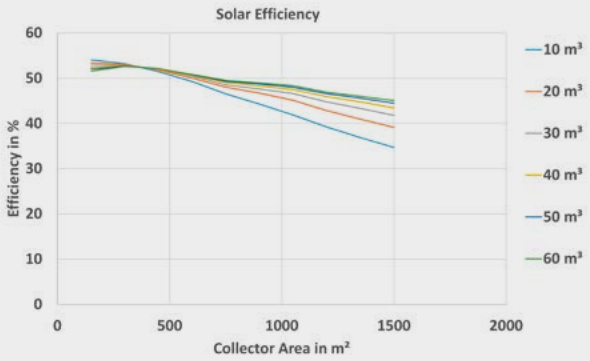


Figure 128:
Sensitivity analysis between collector area and storage tank size to determine solar fraction for vacuum tube collectors (CPC), industrial case (IS1)

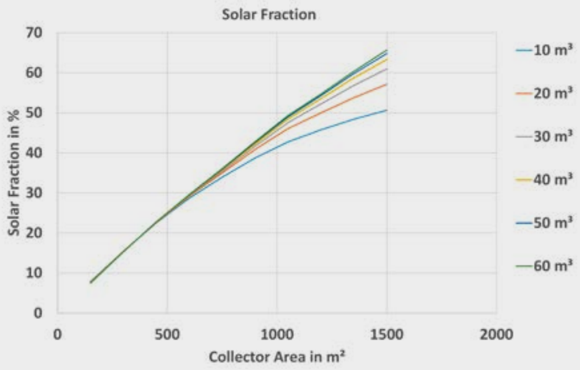


Figure 129:
Sensitivity analysis between collector area and storage tank size to determine solar energy savings for vacuum tube collectors (CPC), industrial case (IS1), Sfax

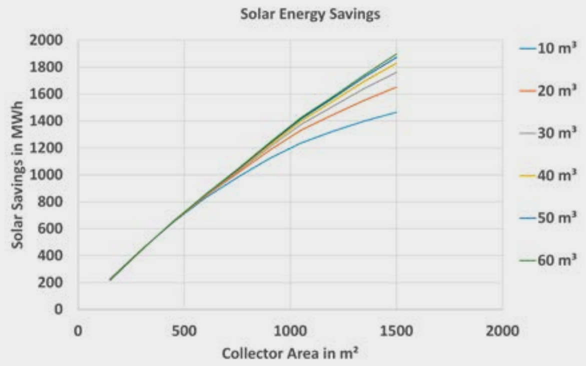


Table 113: Maximum net present value depending on solar thermal system size and storage capacity system, vacuum tube collectors (CPC), industrial case (IS1), Sfax

NPV [TD*1000]	150 m²	300 m²	450 m²	600 m²	750 m²	900 m²	1050 m²	1200 m²	1350 m²	1500 m²
10 m³	-94	-140	-181	-218	-256	-284	-326	-413	-504	-599
20 m³	-129	-175	-212	-244	-271	-278	-298	-367	-436	-510
30 m³	-164	-210	-244	-273	-297	-297	-303	-359	-412	-472
40 m³	-199	-244	-278	-305	-324	-320	-321	-368	-411	-461
60 m³	-269	-312	-344	-370	-385	-377	-371	-414	-447	-484
Maximum	-94	-140	-181	-218	-256	-278	-298	-359	-411	-461

Table 114: Economic evaluation of best economic cases depending on system size and storage volume, Sfax

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
150	10	1212	140,5	-93.559	2,2	55,9	16,8
300	10	1194	127,5	-140.018	3,3	42,1	15,5
450	10	1155	122,9	-180.628	3,7	38,6	15,0
600	10	1106	120,9	-217.920	3,9	37,2	14,8
750	10	1046	120,7	-256.396	3,9	37,1	14,8
900	20	1050	117,3	-278.170	4,3	34,8	14,4
1050	20	1015	115,7	-297.500	4,4	33,8	14,3
1200	30	1006	117,7	-359.380	4,2	35,1	14,5
1350	40	1005	118,2	-410.821	4,2	35,4	14,5
1500	40	976	119,5	-461.160	4,0	36,3	14,7

Figure 130:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Sfax area with vacuum tube collectors (CPC), industrial case (IS1)

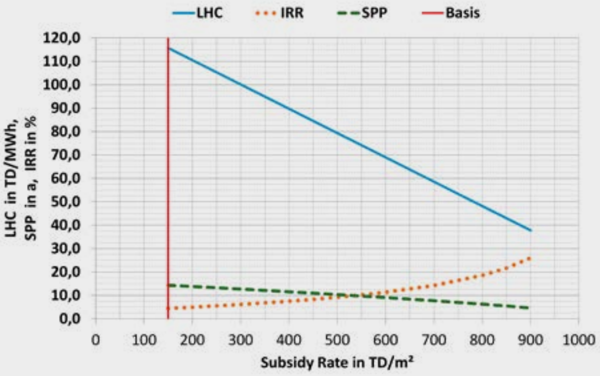
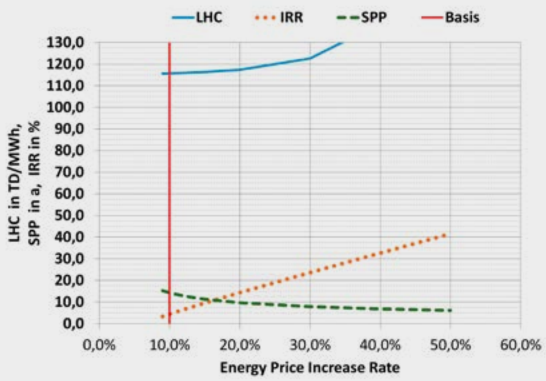


Figure 131:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Sfax area with vacuum tube collectors (CPC), industrial case (IS1)

Figure 132:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Sfax area with vacuum tube collectors (CPC), industrial case (IS1)



10.5.1.2. Location: Tunis, collector type: CPC

Figure 133:
Sensitivity analysis between collector area and storage tank size to determine system efficiency for vacuum tube collectors (CPC), industrial case (IS1), Tunis area

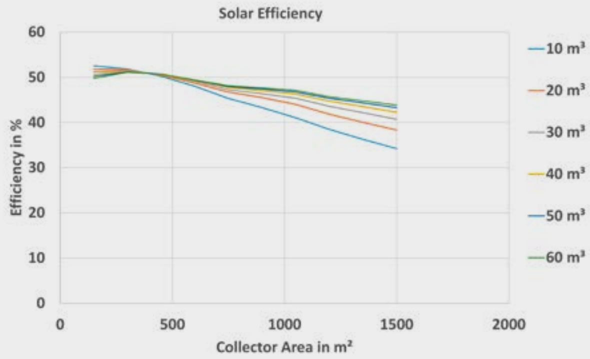


Figure 134:
Sensitivity analysis between collector area and storage tank size to determine the solar fraction for vacuum tube collectors (CPC), industrial case (IS1), Tunis area

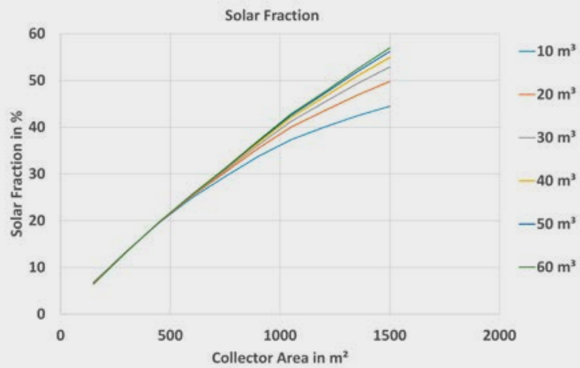


Figure 135:
Sensitivity analysis between collector area and storage tank size to determine energy savings through solar for vacuum tube collectors (CPC), industrial case (IS1), Tunis area

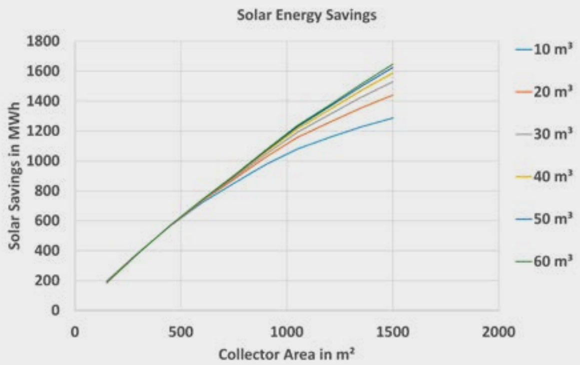


Table 115: Maximum net present value depending on solar thermal system size and storage capacity system, vacuum tube collectors (CPC), industrial case (IS1), Tunis area

NPV [TD*1000]	150 m²	300 m²	450 m²	600 m²	750 m²	900 m²	1050 m²	1200 m²	1350 m²	1500 m²
10 m³	-113	-179	-236	-289	-341	-379	-429	-523	-617	-715
20 m³	-149	-213	-268	-317	-358	-380	-412	-491	-568	-648
30 m³	-184	-248	-301	-347	-386	-401	-423	-490	-555	-624
40 m³	-219	-282	-334	-379	-413	-425	-441	-502	-559	-620
60 m³	-289	-351	-401	-444	-476	-484	-494	-550	-598	-648
Maximum	-113	-179	-236	-289	-341	-379	-412	-490	-555	-620

Table 116: Economic evaluation of best economic cases depending on system size and storage volume, Tunis area

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
150	10	1050	162,2	-113.388	0,7	100,0	19,0
300	10	1037	146,8	-178.603	1,7	66,7	17,5
450	10	1005	141,3	-235.933	2,2	57,5	16,9
600	10	961	139,2	-289.254	2,3	54,7	16,7
750	10	908	139,1	-341.194	2,3	54,8	16,7
900	10	867	137,5	-378.834	2,4	52,8	16,6
1050	20	882	133,2	-411.941	2,8	47,9	16,1
1200	30	872	135,7	-490.330	2,6	50,6	16,4
1350	30	844	137,6	-555.017	2,4	53,1	16,6
1500	40	846	137,7	-619.682	2,4	53,2	16,6

Figure 136:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Tunis area with vacuum tube collectors (CPC), industrial case (IS1), Tunis area

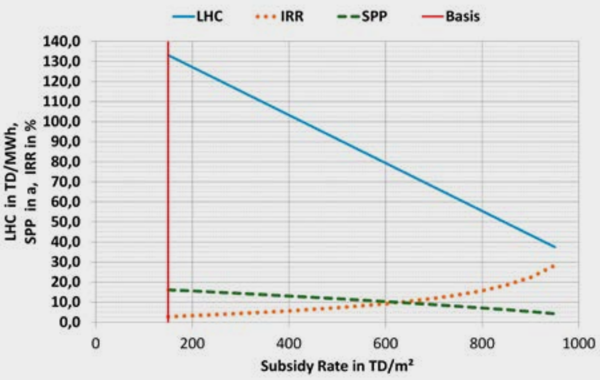
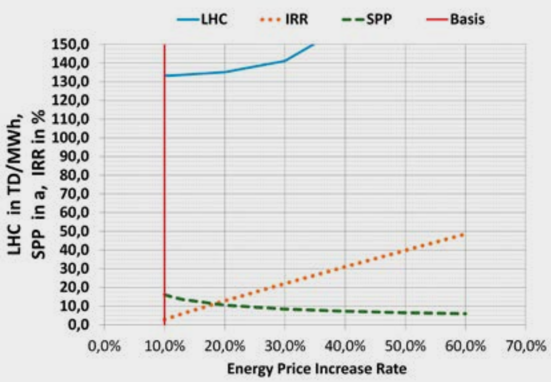


Figure 137:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Tunis area with vacuum tube collectors (CPC), industrial case (IS1)

Figure 138:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Tunis area with vacuum tube collectors (CPC), industrial case (IS1)



Location: Tunis, collector type: LFC

Figure 139:
Sensitivity analysis between collector area and storage tank size to determine system efficiency for linear Fresnel collectors (LFC), industrial case (IS1), Tunis area

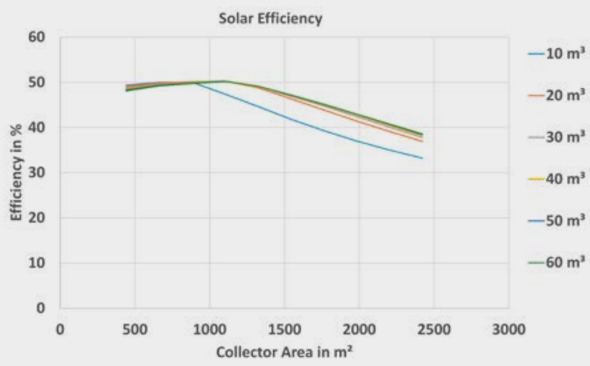


Figure 140:
Sensitivity analysis between collector area and storage tank size to determine solar fraction for linear Fresnel collectors (LFC), industrial case (IS1), Tunis area

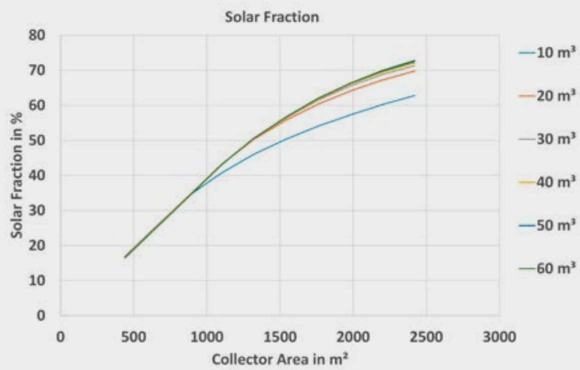


Figure 141:
Sensitivity analysis between collector area and storage tank size to determine solar energy savings for linear Fresnel collectors (LFC), industrial case (IS1), Tunis area

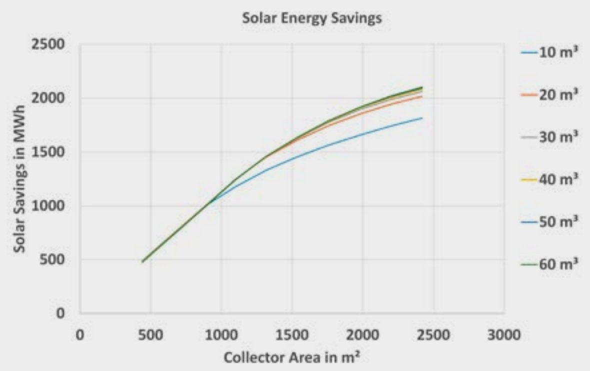


Table 117: Maximum net present value depending on solar thermal system size and storage capacity system, linear Fresnel collectors (LFC), industrial case (IS1), Tunis area

NPV [TD*1000]	440 m^2	660 m^2	880 m^2	1100 m^2	1320 m^2	1540 m^2	1760 m^2	1980 m^2	2200 m^2	2420 m^2
10 m^3	-733	-998	-1179	-1333	-1438	-1494	-1491	-1430	-1605	-1813
20 m^3	-773	-1038	-1216	-1325	-1396	-1429	-1411	-1339	-1511	-1718
30 m^3	-812	-1077	-1255	-1363	-1430	-1457	-1428	-1350	-1520	-1728
40 m^3	-851	-1116	-1294	-1401	-1466	-1491	-1460	-1378	-1546	-1752
60 m^3	-930	-1195	-1373	-1480	-1542	-1564	-1531	-1448	-1611	-1812
Maximum	-733	-998	-1179	-1325	-1396	-1429	-1411	-1339	-1511	-1718

Table 118: Economic evaluation of best economic cases depending on system size and storage volume, Tunis area

Collector area [m^2]	Extra volume [m^3]	Spec. solar yield [kWh/ m^2]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
440	10	888	284,0	-732.885	< 0	> 100	40,7
660	10	901	263,3	-998.323	< 0	> 100	36,8
880	10	903	242,8	-1.179.134	< 0	> 100	33,3
1100	10	856	235,5	-1.333.420	< 0	> 100	32,2
1320	20	881	212,9	-1.396.184	< 0	> 100	28,5
1540	20	838	203,1	-1.429.455	< 0	> 100	27,1
1760	20	793	192,9	-1.411.025	< 0	> 100	25,6
1980	20	748	181,6	-1.339.295	< 0	> 100	24,1
2200	20	706	188,8	-1.511.197	< 0	> 100	25,2
2420	20	667	198,6	-1.718.292	< 0	> 100	26,8

Figure 142: Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Tunis area with linear Fresnel collector (LFC), industrial case (IS1)

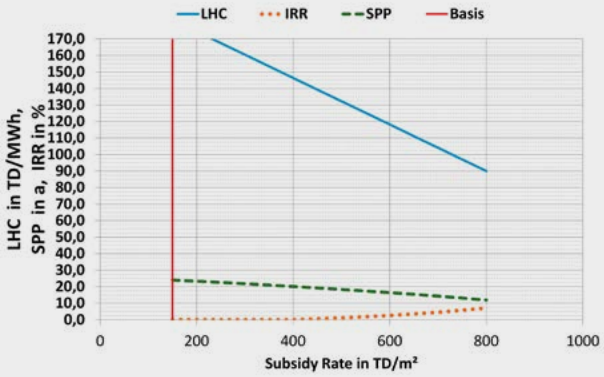
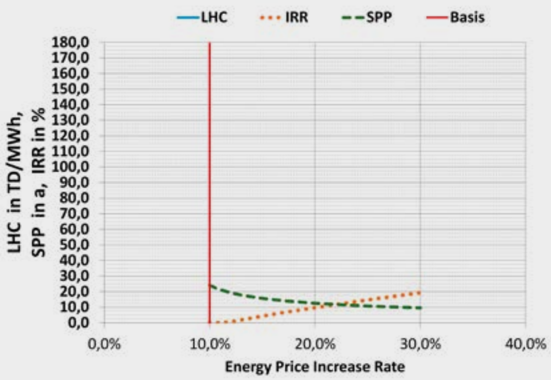


Figure 143:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Tunis area with linear Fresnel collector (LFC), industrial case (IS1)

Figure 144:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Tunis area with linear Fresnel collector (LFC), industrial case (IS1)



10.5.2. IS2 – Food industry, yeast production

10.5.2.1. Location: Sfax, collector type: FPC

Figure 145:
Sensitivity analysis between collector area and storage tank size to determine system efficiency for flat plate collectors (FPC), industrial case (IS2), Sfax area

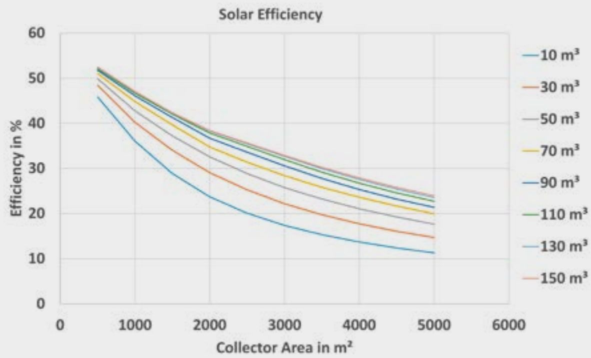


Figure 146:
Sensitivity analysis between collector area and storage tank size to determine the solar fraction for flat plate collectors (FPC), industrial case (IS2), Sfax area

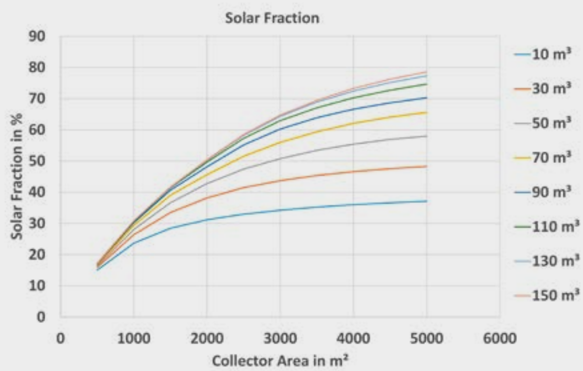


Figure 147:
Sensitivity analysis between collector area and storage tank size to determine solar energy savings for flat plate collectors (FPC), industrial case (IS2), Sfax area

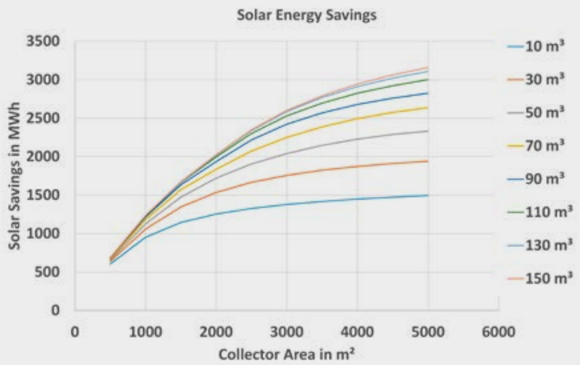


Table 119: Maximum net present value depending on solar thermal system size and storage capacity system, flat plate collectors (FPC), industrial case (IS2), Sfax area

NPV [TD*1000]	500 m²	1000 m²	1500 m²	2000 m²	2500 m²	3000 m²	3500 m²	4000 m²	4500 m²	5000 m²
10 m³	-6	-94	-307	-555	-801	-1035	-1248	-1437	-1601	-1740
30 m³	-14	-44	-184	-372	-571	-775	-966	-1142	-1296	-1427
50 m³	-33	-25	-120	-260	-420	-589	-749	-901	-1037	-1157
70 m³	-55	-17	-78	-205	-324	-459	-597	-727	-848	-955
90 m³	-81	-25	-63	-161	-245	-360	-490	-619	-739	-843
110 m³	-111	-47	-75	-148	-214	-310	-426	-539	-647	-740
130 m³	-143	-74	-102	-165	-220	-301	-402	-506	-604	-691
150 m³	-174	-106	-132	-192	-244	-322	-419	-514	-606	-686
Maximum	-6	-17	-63	-148	-214	-301	-402	-506	-604	-686

Table 120: Economic evaluation of best economic cases depending on system size and storage volume, Sfax area

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
500	10	1029	97,3	-5.677	7,9	20,4	11,2
1000	70	1004	97,9	-16.599	7,8	20,6	11,3
1500	90	926	100,9	-62.649	7,4	21,6	11,6
2000	110	848	105,4	-148.198	6,8	23,2	12,0
2500	110	783	107,7	-213.939	6,6	24,1	12,2
3000	110	717	111,4	-310.207	6,2	25,6	12,6
3500	130	672	114,2	-402.164	5,8	26,8	12,9
4000	130	619	117,7	-505.974	5,5	28,4	13,2
4500	130	571	121,0	-604.203	5,1	30,0	13,6
5000	130	528	123,7	-690.614	4,8	31,4	13,9

Figure 148:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Sfax area with flat plate collectors (FPC), industrial case (IS2)

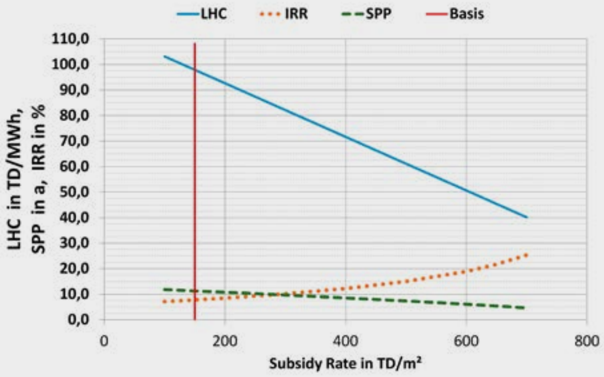


Figure 149:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Sfax area with flat plate collectors (FPC), industrial case (IS2)

Figure 150:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Sfax area with flat plate collectors (FPC), industrial case (IS2)

10.5.2.2. Location: Tunis, collector type: CPC

Figure 151:
Sensitivity analysis comparing collector area and storage tank size to determine system efficiency for vacuum tube collectors (CPC), industrial case (IS2), Tunis area

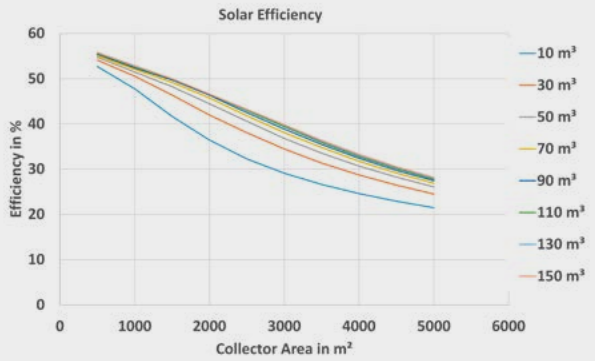


Figure 152:
Sensitivity analysis between collector area and storage tank size to determine solar fraction for vacuum tube collectors (CPC), industrial case (IS2), Tunis area

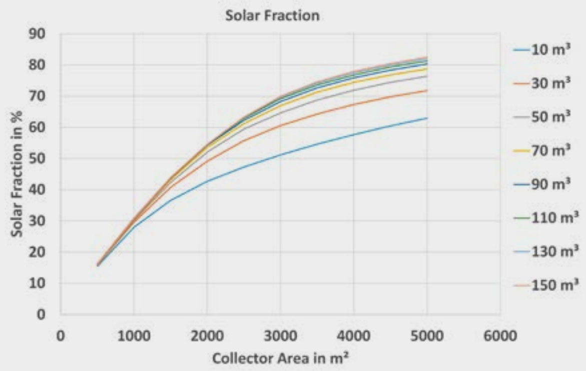


Figure 153:
Sensitivity analysis between collector area and storage tank size to determine solar energy savings for vacuum tube collectors (CPC), industrial case (IS2), Tunis area

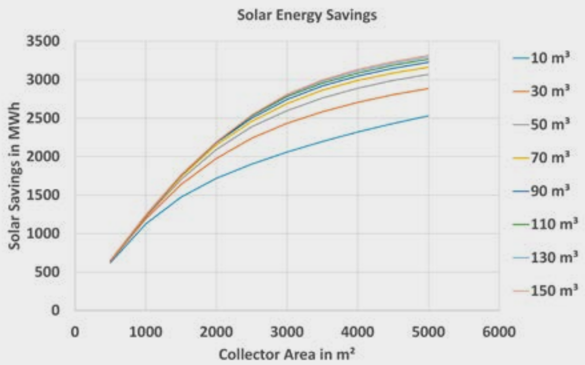


Table 121: Maximum net present value depending on solar thermal system size and storage capacity system, vacuum tube collectors (CPC), industrial case (IS2), Tunis area

NPV [TD*1000]	500 m²	1000 m²	1500 m²	2000 m²	2500 m²	3000 m²	3500 m²	4000 m²	4500 m²	5000 m²
10 m³	-163	-198	-399	-642	-895	-1133	-1348	-1537	-1698	-1830
30 m³	-185	-183	-305	-476	-668	-877	-1082	-1271	-1442	-1589
50 m³	-212	-199	-288	-419	-585	-783	-977	-1163	-1332	-1481
70 m³	-243	-222	-296	-407	-565	-745	-931	-1118	-1291	-1441
90 m³	-273	-250	-315	-418	-566	-738	-923	-1107	-1277	-1426
110 m³	-305	-281	-343	-444	-579	-742	-929	-1113	-1280	-1429
130 m³	-338	-311	-375	-476	-603	-760	-943	-1125	-1293	-1440
150 m³	-370	-341	-408	-510	-634	-786	-964	-1143	-1312	-1457
Maximum	-163	-183	-288	-407	-565	-738	-923	-1107	-1277	-1426

Table 122: Economic evaluation of best economic cases depending on system size and storage volume, Tunis area

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
500	10	1053	128,7	-162.660	4,5	33,6	14,2
1000	30	1010	115,2	-182.553	5,8	27,1	13,0
1500	50	965	117,1	-288.002	5,6	27,9	13,2
2000	70	915	119,6	-406.541	5,3	29,1	13,4
2500	70	836	124,6	-564.843	4,8	31,6	13,9
3000	90	777	129,5	-737.503	4,4	34,2	14,4
3500	90	709	135,4	-922.599	3,8	37,9	14,9
4000	90	648	141,2	-1.107.377	3,3	42,2	15,5
4500	90	595	146,5	-1.276.957	2,9	46,8	16,0
5000	90	549	151,0	-1.425.806	2,5	51,5	16,5

Figure 154:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Tunis area with vacuum tube collectors (CPC), industrial case (IS2)

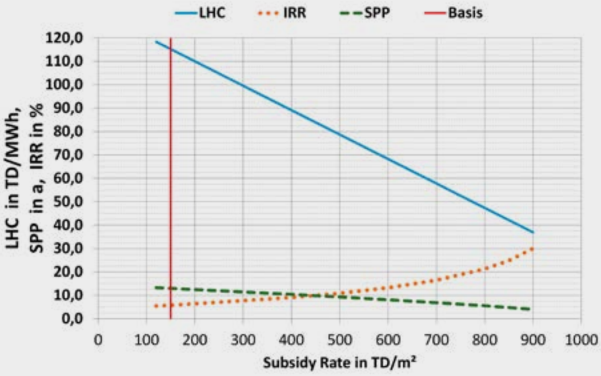
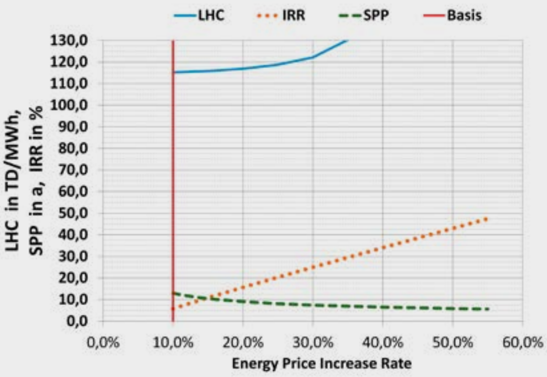


Figure 155:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Tunis area with vacuum tube collectors (CPC), industrial case (IS2)

Figure 156:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Tunis area with vacuum tube collectors (CPC), industrial case (IS2)



10.5.2.3. Location: Tunis, collector type: FPC

Figure 157:
Sensitivity analysis between collector area and storage tank size to determine system efficiency for flat plate collectors (FPC), industrial case (IS2), Tunis area

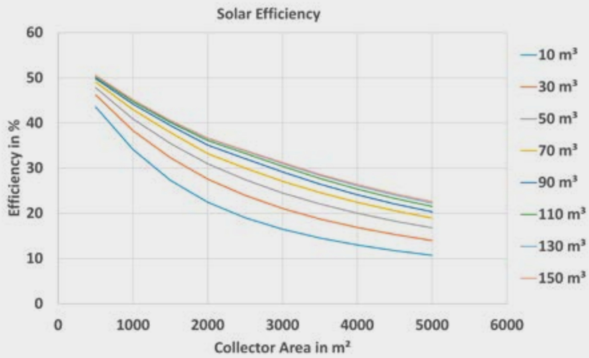


Figure 158:
Sensitivity analysis between collector area and storage tank size to determine solar fraction for flat plate collectors (FPC), industrial case (IS2), Tunis area

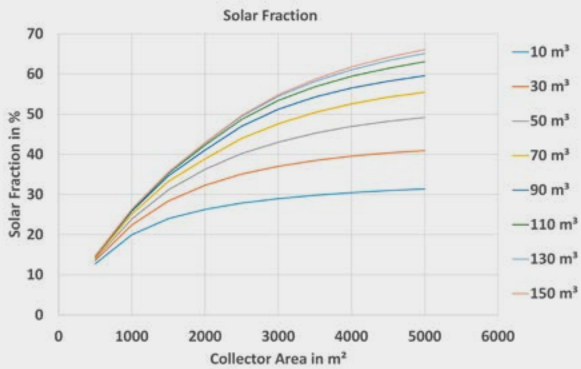


Figure 159:
Sensitivity analysis between collector area and storage tank size to determine solar energy savings for flat plate collectors (FPC), industrial case (IS2)

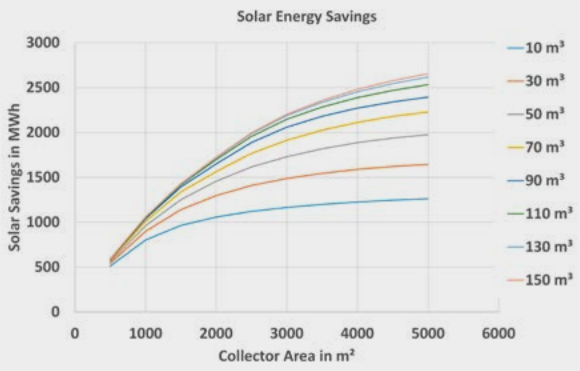


Table 123: Maximum net present value depending on solar thermal system size and storage capacity system, flat plate collectors (FPC), industrial case (IS2), Tunis area

NPV [TD*1000]	500 m²	1000 m²	1500 m²	2000 m²	2500 m²	3000 m²	3500 m²	4000 m²	4500 m²	5000 m²
10 m³	-78	-209	-446	-708	-961	-1200	-1417	-1610	-1778	-1920
30 m³	-88	-168	-344	-555	-770	-984	-1183	-1362	-1521	-1657
50 m³	-107	-154	-291	-464	-644	-830	-1004	-1164	-1309	-1433
70 m³	-129	-150	-258	-416	-560	-721	-877	-1023	-1155	-1271
90 m³	-156	-161	-250	-382	-500	-641	-790	-933	-1065	-1176
110 m³	-186	-185	-266	-378	-481	-607	-745	-877	-999	-1102
130 m³	-218	-212	-292	-398	-493	-609	-737	-860	-973	-1071
150 m³	-250	-244	-320	-425	-518	-630	-755	-872	-982	-1075
Maximum	-78	-150	-250	-378	-481	-607	-737	-860	-973	-1071

Table 124: Economic evaluation of best economic cases depending on system size and storage volume, Tunis area

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
500	10	871	114,9	-77.585	5,8	27,0	12,9
1000	70	858	114,6	-149.904	5,8	26,9	12,9
1500	90	789	118,4	-249.741	5,4	28,6	13,3
2000	110	722	123,8	-378.370	4,9	31,2	13,8
2500	110	665	126,7	-481.257	4,6	32,8	14,1
3000	110	608	131,2	-606.921	4,2	35,5	14,6
3500	130	567	135,3	-737.278	3,8	38,2	15,0
4000	130	521	139,7	-860.477	3,4	41,5	15,4
4500	130	481	143,6	-972.659	3,1	44,8	15,8
5000	130	445	146,9	-1.070.734	2,8	48,1	16,2

Figure 160:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), industrial case (IS2)

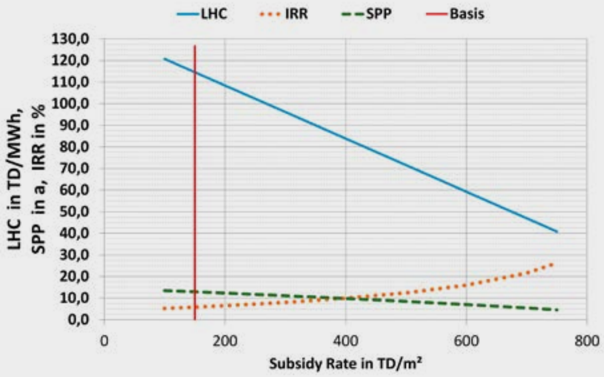


Figure 161:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), industrial case (IS2)

Figure 162:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Tunis area with flat plate collectors (FPC), industrial case (IS2)

10.5.3. IS3 – Textile industry

10.5.3.1. Location: Sfax, collector type: LFC

Figure 163:
Solar fraction and solar efficiency over collector area for linear Fresnel collectors (LFC), industrial case (IS3), Tunis and Sfax compared

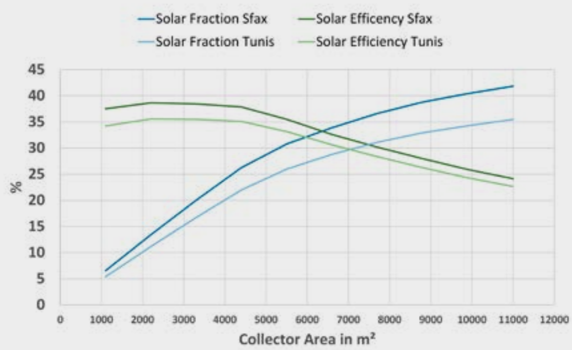


Figure 164:
Solar savings of collector area for linear Fresnel collectors (LFC), industrial case (IS3), Sfax area

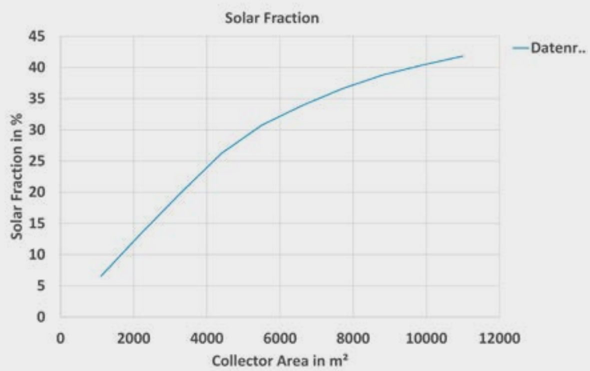


Table 125: Economic evaluation of best economic cases depending on system size and storage volume, Sfax area

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
1100	0	747	279,4	-1.460.175	< 0	> 100	36,9
2200	0	760	180,3	-1.398.981	< 0	> 100	22,2
3300	0	757	176,4	-1.998.559	< 0	> 100	21,7
4400	0	746	174,4	-2.562.554	< 0	> 100	21,4
5500	0	701	180,6	-3.236.620	< 0	> 100	22,3
6600	0	644	191,1	-3.993.159	< 0	> 100	23,8
7700	0	597	200,4	-4.721.706	< 0	> 100	25,2
8800	0	553	209,8	-5.437.193	< 0	> 100	26,7
9900	0	513	219,7	-6.143.402	< 0	> 100	28,3
11000	0	478	228,4	-6.796.862	< 0	> 100	29,8

Figure 165:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Sfax area with linear Fresnel collector (LFC), industrial case (IS3)

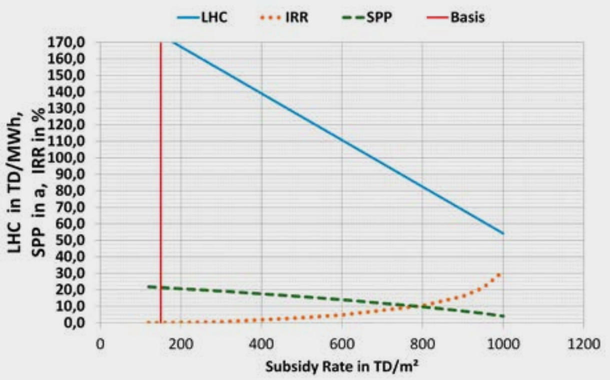


Figure 167:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Sfax area with linear Fresnel collector (LFC), industrial case (IS3)

Figure 166:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Sfax area with linear Fresnel collector (LFC), industrial case (IS3)

10.5.3.2. Location: Tunis, collector type: CPC

Figure 168:
Solar efficiency and solar fraction according to collector area for flat plate collectors (CPC), industrial case (IS3), Tunis area

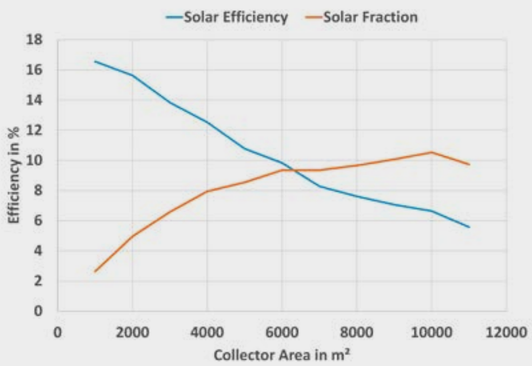


Table 126: Economic evaluation of best economic cases depending on system size and storage volume, Tunis area

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
1000	0	331	354,2	-823.652	< 0	> 100	36,8
2000	0	311	350,4	-1.525.624	< 0	> 100	36,7
3000	0	275	366,5	-2.148.316	< 0	> 100	38,6
4000	0	249	372,0	-2.643.079	< 0	> 100	39,6
5000	0	214	394,0	-3.064.632	< 0	> 100	42,6
6000	0	196	389,1	-3.304.910	< 0	> 100	42,7
7000	0	168	404,7	-3.478.539	< 0	> 100	45,6
8000	0	151	393,9	-3.463.590	< 0	> 100	45,4
9000	0	140	366,0	-3.278.735	< 0	> 100	42,9
10000	0	132	326,9	-2.934.541	< 0	> 100	39,0
11000	0	110	315,2	-2.571.244	< 0	> 100	39,5

Figure 169:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Tunis area with vacuum tube collectors (CPC), industrial case (IS3)

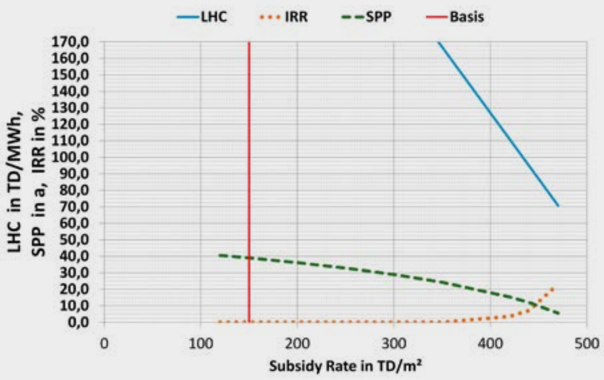


Figure 170:
Sensitivity analysis of energy price effects (TD/MWh) on LHC, IRR, SPP, Tunis area with vacuum tube collectors (CPC), industrial case (IS3)

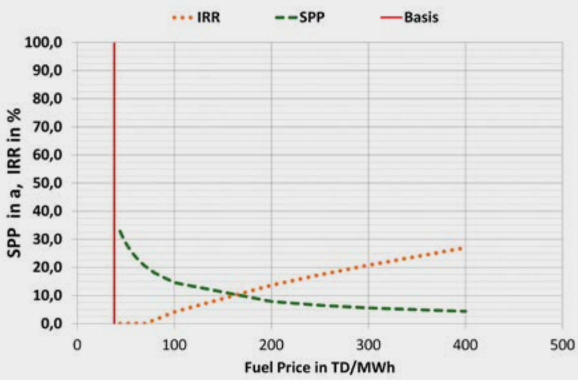
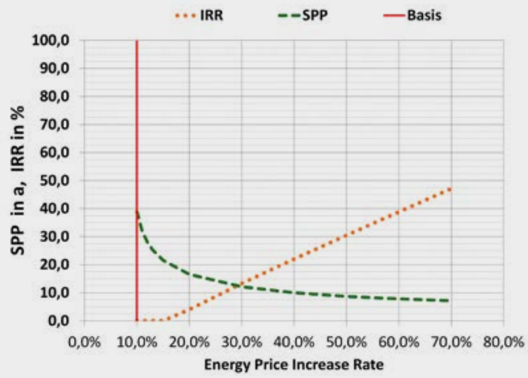


Figure 171:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Tunis area with vacuum tube collectors (CPC), industrial case (IS3)



10.5.3.3. Location: Tunis, collector type: LFC

Table 127: Economic evaluation of best economic cases depending on system size and storage volume, Tunis area

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
1100	0	615	339,3	-1.586.777	< 0	> 100	49,3
2200	0	632	216,8	-1.644.906	< 0	> 100	27,5
3300	0	631	211,5	-2.359.700	< 0	> 100	26,7
4400	0	624	208,4	-3.028.975	< 0	> 100	26,3
5500	0	591	214,1	-3.763.488	< 0	> 100	27,2
6600	0	547	225,1	-4.553.434	< 0	> 100	29,0
7700	0	506	236,2	-5.328.451	< 0	> 100	30,9
8800	0	469	247,5	-6.085.475	< 0	> 100	32,9
9900	0	434	259,4	-6.821.043	< 0	> 100	35,2
11000	0	405	269,5	-7.495.923	< 0	> 100	37,4

Figure 172:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Tunis area with linear Fresnel collector (LFC), industrial case (IS3)

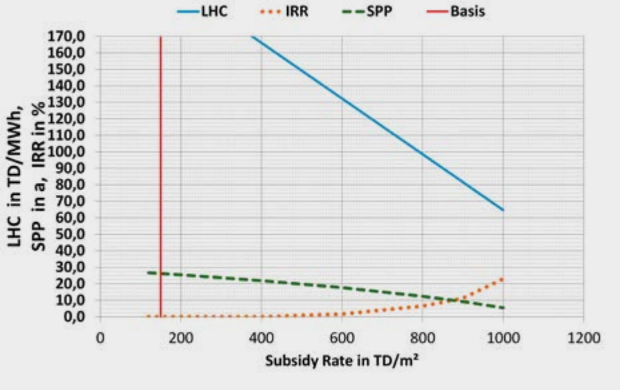


Figure 173:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Tunis area with linear Fresnel collector (LFC), industrial case (IS3)

Figure 174:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Tunis area with linear Fresnel collector (LFC), industrial case (IS3)

10.5.4. IS4 – Construction industry, brick production

10.5.4.1. Location: Sfax, collector type: LFC

Figure 175:
Sensitivity analysis between collector area and storage tank size to determine system efficiency for linear Fresnel collectors (LFC), industrial case (IS4), Sfax area

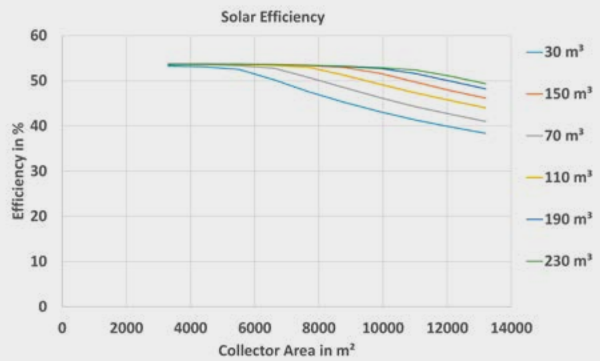


Figure 176:
Sensitivity analysis between collector area and storage tank size to determine the solar fraction for linear Fresnel collectors (LFC), industrial case (IS4)

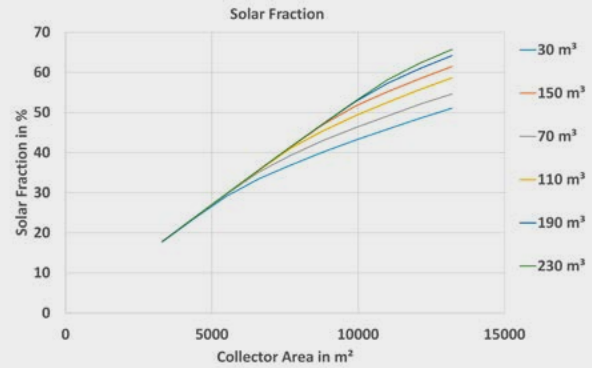


Figure 177:
Sensitivity analysis between collector area and storage tank size to determine solar energy savings for linear Fresnel collectors (LFC), industrial case (IS4), Sfax area

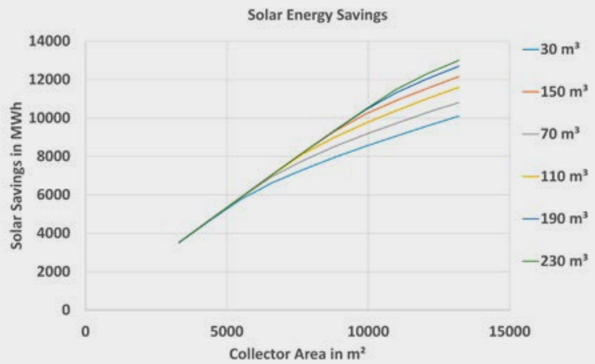


Table 128: Maximum net present value depending on solar thermal system size and storage capacity system, flat plate collectors (LFC), industrial case (IS4), Sfax area

NPV [TD*1000]	3300 m²	4400 m²	5500 m²	6600 m²	7700 m²	8800 m²	9900 m²	11000 m²	12100 m²	13200 m²
30 m³	-1778	-2200	-2585	-3068	-3590	-4078	-4535	-5262	-6024	-6805
70 m³	-1918	-2333	-2686	-3006	-3429	-3860	-4281	-4983	-5715	-6491
110 m³	-2065	-2474	-2820	-3105	-3351	-3697	-4050	-4696	-5394	-6123
150 m³	-2216	-2621	-2963	-3244	-3466	-3646	-3888	-4502	-5194	-5909
190 m³	-2369	-2773	-3113	-3392	-3609	-3778	-3896	-4383	-5018	-5709
230 m³	-2523	-2925	-3265	-3541	-3756	-3920	-4029	-4421	-4996	-5660
Maximum	-1778	-2200	-2585	-3006	-3351	-3646	-3888	-4383	-4996	-5660

Table 129: Economic evaluation of best economic cases depending on system size and storage volume, Sfax area

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
3300	30	1061	122,6	-1.778.017	0,1	> 100	19,9
4400	30	1059	118,8	-2.199.855	0,5	> 100	19,3
5500	30	1049	116,2	-2.584.772	0,8	> 100	18,9
6600	70	1053	114,6	-3.005.971	1,0	> 100	18,6
7700	150	1064	113,6	-3.465.561	1,1	89,3	18,4
8800	190	1060	111,7	-3.777.731	1,3	78,6	18,1
9900	230	1056	109,7	-4.029.013	1,5	70,1	17,8
11000	230	1046	109,6	-4.420.916	1,6	69,8	17,8
12100	230	1018	111,8	-4.995.978	1,3	79,6	18,1
13200	230	984	115,0	-5.660.018	0,9	100,0	18,7

Figure 178:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Sfax area with linear Fresnel collector (LFC), industrial case (IS4)

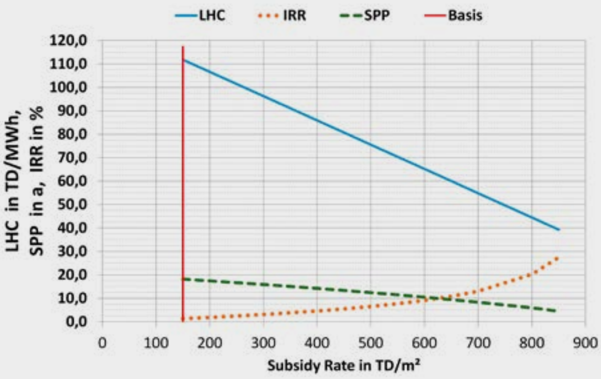


Figure 179:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Sfax area with linear Fresnel collector (LFC), industrial case (IS4)

Figure 180:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Sfax area with linear Fresnel collector (LFC), industrial case (IS4)

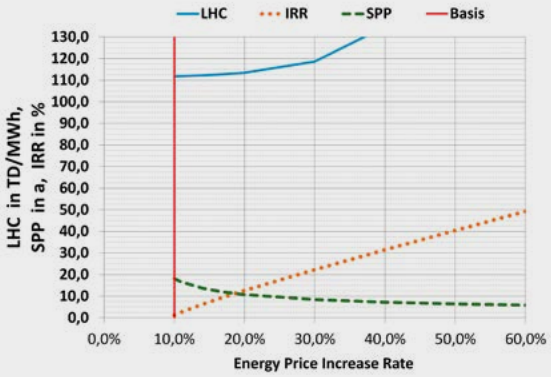
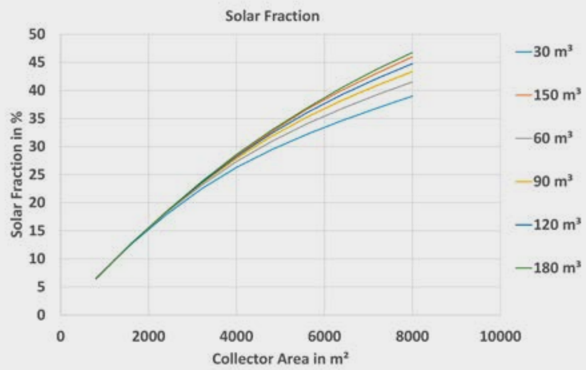


Figure 182:
Sensitivity analysis between collector area and storage tank size to determine solar fraction for vacuum tube collectors (CPC), industrial case (IS4), Tunis area



10.5.4.2. Location: Tunis, collector type: CPC

Figure 181:
Sensitivity analysis between collector area and storage tank size to determine system efficiency for vacuum tube collectors (CPC), industrial case (IS4), Tunis area

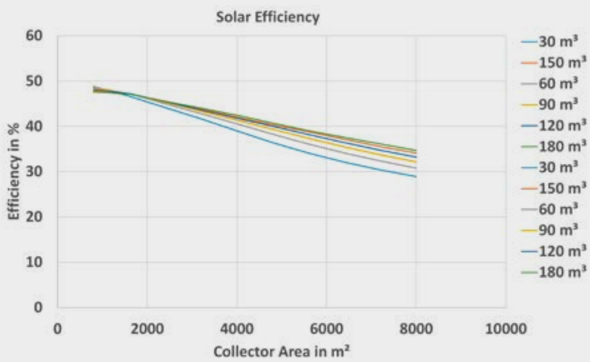


Figure 183:
Sensitivity analysis between collector area and storage tank size to determine solar energy savings for vacuum tube collectors (CPC), industrial case (IS4), Tunis area

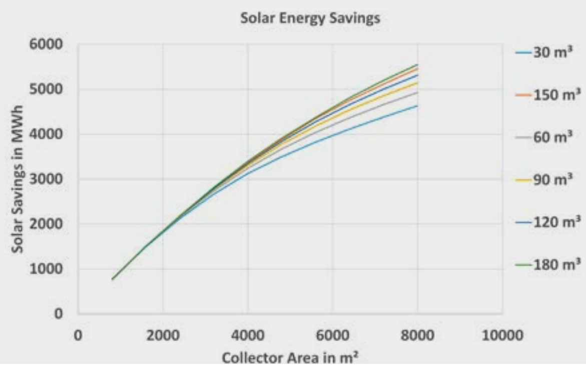


Table 130: Maximum net present value depending on solar thermal system size and storage capacity system, vacuum tube collectors (CPC), industrial case (IS4), Tunis area

NPV [TD*1000]	800 m²	1600 m²	2400 m²	3200 m²	4000 m²	4800 m²	5600 m²	6400 m²	7200 m²	8000 m²
30 m³	-496	-735	-989	-1199	-1374	-1506	-1826	-2240	-2669	-3108
60 m³	-599	-828	-1067	-1255	-1397	-1493	-1784	-2176	-2588	-3017
90 m³	-702	-929	-1158	-1335	-1457	-1526	-1793	-2163	-2560	-2975
120 m³	-806	-1029	-1254	-1423	-1534	-1586	-1832	-2185	-2566	-2966
150 m³	-910	-1131	-1351	-1514	-1619	-1663	-1886	-2226	-2593	-2973
180 m³	-1013	-1232	-1453	-1606	-1701	-1741	-1971	-2291	-2639	-3014
Maximum	-496	-735	-989	-1199	-1374	-1493	-1784	-2163	-2560	-2966

Table 131: Economic evaluation of best economic cases depending on system size and storage volume, Tunis area

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
800	30	976	136,1	-496.137	0,1	> 100	19,9
1600	30	935	120,9	-735.327	1,4	79,4	18,0
2400	30	885	118,1	-988.648	1,6	70,8	17,7
3200	30	834	116,4	-1.198.851	1,7	66,5	17,5
4000	30	781	115,4	-1.373.767	1,8	64,5	17,4
4800	60	765	111,9	-1.493.388	2,2	57,4	16,9
5600	60	722	115,6	-1.784.247	1,8	65,5	17,4
6400	90	710	119,3	-2.162.945	1,4	76,6	17,9
7200	90	675	124,6	-2.560.110	0,9	> 100	18,6
8000	120	664	127,9	-2.966.203	0,6	> 100	19,1

Figure 184:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Tunis area with vacuum tube collectors (CPC), industrial case (IS4)

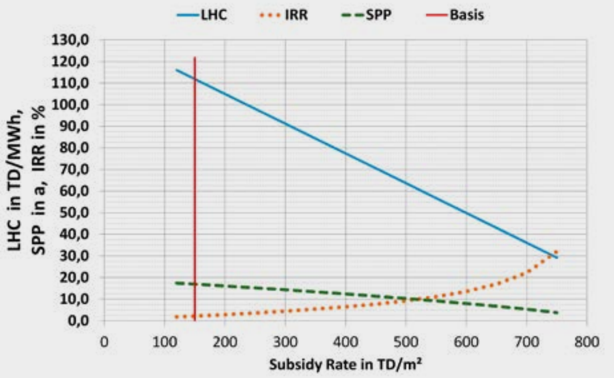


Figure 185:
Sensitivity analysis of fuel price effects (TD/MWh) on LHC, IRR, SPP, Tunis area with vacuum tube collectors (CPC), industrial case (IS4)

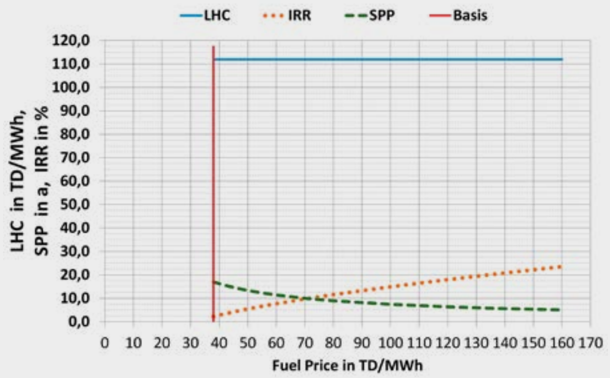


Figure 186:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Tunis area with vacuum tube collectors (CPC), industrial case (IS4)

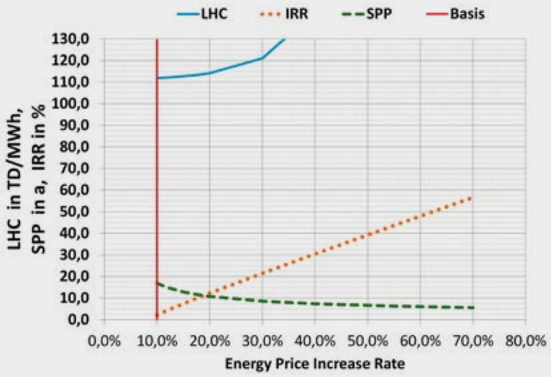
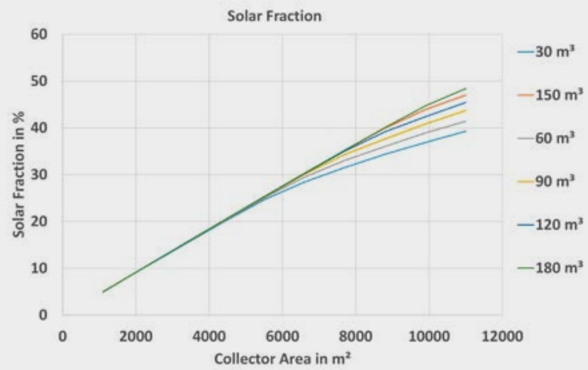


Figure 188:
Sensitivity analysis between collector area and storage tank size to determine the solar fraction for vacuum tube collectors (CPC), industrial case (IS4), Tunis area



10.5.4.3. Location: Tunis, collector type: LFC

Figure 187:
Sensitivity analysis between collector area and storage tank size to determine system efficiency for linear Fresnel collectors (LFC), industrial case (IS4), Tunis area

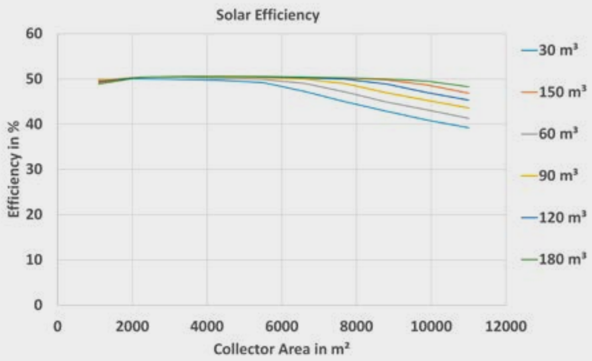


Figure 189:
Sensitivity analysis between collector area and storage tank size to determine solar energy savings for linear Fresnel collectors (LFC), industrial case (IS4), Tunis area

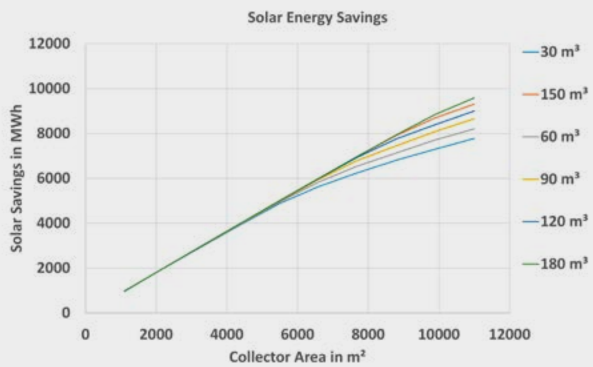


Table 132: Maximum net present value depending on solar thermal system size and storage capacity system, linear Fresnel collector (LFC), industrial case (IS4), Tunis area

NPV [TD*1000]	1100 m²	2200 m²	3300 m²	4400 m²	5500 m²	6600 m²	7700 m²	8800 m²	9900 m²	11000 m²
30 m³	-1534	-1521	-2127	-2667	-3161	-3716	-4285	-4822	-5334	-6104
60 m³	-1650	-1629	-2225	-2762	-3236	-3694	-4202	-4722	-5180	-5938
90 m³	-1764	-1743	-2332	-2860	-3326	-3733	-4150	-4626	-5047	-5755
120 m³	-1880	-1856	-2443	-2965	-3427	-3825	-4171	-4537	-4960	-5643
150 m³	-1996	-1969	-2556	-3077	-3534	-3930	-4265	-4552	-4872	-5554
180 m³	-2112	-2082	-2670	-3190	-3644	-4040	-4370	-4648	-4885	-5485
Maximum	-1534	-1521	-2127	-2667	-3161	-3694	-4150	-4537	-4872	-5485

Table 133: Economic evaluation of best economic cases depending on system size and storage volume, Tunis area

Collector area [m²]	Extra volume [m³]	Spec. solar yield [kWh/m²]	LHC [TD / MWh]	NPV [TD]	IRR [%]	DPP [y]	SPP [y]
1100	30	897	233,0	-1.533.687	< 0	> 100	42,9
2200	30	902	149,8	-1.521.010	< 0	> 100	24,9
3300	30	900	144,5	-2.126.557	< 0	> 100	24,0
4400	30	897	140,3	-2.667.024	< 0	> 100	23,2
5500	30	889	137,2	-3.161.307	< 0	> 100	22,7
6600	60	885	135,7	-3.693.885	< 0	> 100	22,4
7700	90	884	133,3	-4.150.063	< 0	> 100	22,0
8800	120	882	130,6	-4.537.445	< 0	> 100	21,5
9900	150	879	128,1	-4.872.150	< 0	> 100	21,0
11000	180	872	129,4	-5.485.398	< 0	> 100	21,3

Figure 190:
Sensitivity analysis of collector subsidy rate effects (TD/m²) on LHC, IRR, SPP, Tunis area with linear Fresnel collector (LFC), industrial case (IS4)

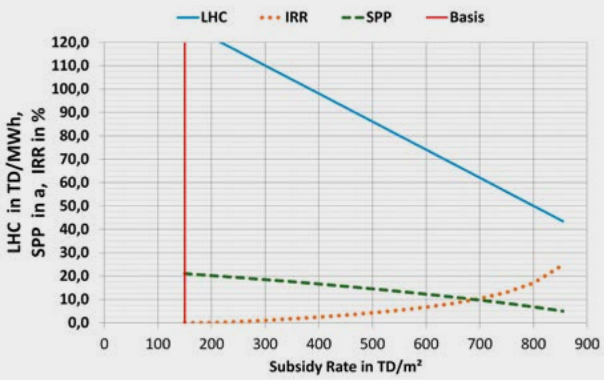


Figure 191:
Sensitivity analysis of energy price effects (TD/MWh) on LHC, IRR, SPP, Tunis area with linear Fresnel collector (LFC), industrial case (IS4)

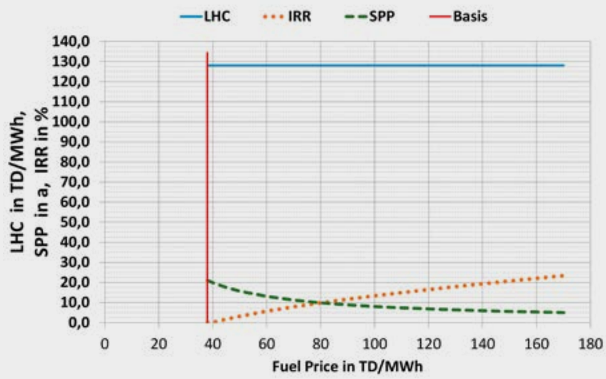


Figure 192:
Sensitivity analysis of relative energy price changes (%) on LHC, IRR, SPP, Tunis area with linear Fresnel collector (LFC), industrial case (IS4)