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Bachelor Thesis

Solar Heat for Industrial Processes in Tunisia: An Economic Assessment with Policy Recommendations

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Chair of Energy Economics

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for listening, advice, patience, support,
understanding, encouragement & happiness
from near and far.

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List of Abbreviations and Symbols

a	Annuity
A_a	Aperture area
ANME	Tunisian Agency for Energy Conservation
AUT	Austria
BSW	German Solar Industry Association
c_1	Heat loss coefficient 1 (W/m²/K)
c_2	Heat loss coefficient 1 (W/m²/K²)
$C_{con,t}$	Consumption costs
CHE	Switzerland
CHP	Combined Heat and Power
CIF	Cash Inflow
C_{inv}	Total investment costs
c_{inv}	Specific total investment costs
COF	Cash Outflow
CSP	Concentrated Solar Power
DASTII	Dissemination of Innovative Solar Thermal Applications for the Tunisian Industry
DEU	Germany
DGE	General Direction of Energy
DLR	German Aerospace Center
DNI	Direct Normal Irradiation
d_{nom}	Nominal discounting factor
d_{real}	Real discounting factor
e	Inflation
EGY	Egypt
ER	Equity ratio
ESCO	Energy Service Company
ESP	Spain
ETAP	Tunisian Company for Oil Activities
ETC	Evacuated Tube Collector
f_a	Annuity factor
FO	Fuel oil
FPC	Flat Plate Collector
FTE	Funds for Energy Transition, former FNME (Funds for Energy Conservation)
G	Solar irradiation
GDP	Gross Domestic Product
GHI	Global Horizontal Irradiation

GIZ	German International Cooperation
GR	Grant rate
G_{tilt}	Global Irradiation on tilted plane
i	Interest rate
IMELS	Italian Ministry for the Environment, Land and Sea
IRR	Internal Rate of Return
LRF	Linear Fresnel Reflector
LT	Lifetime
MEDREC	Mediterranean Reneweable Energy Centre
MENA	Middle East and North Africa
MIEM	Ministry of Industry, Energy, and Mines
n	Loan duration
NCF	Net Cash Flow
NG	Natural gas
NPV	Net Present Value
O&M	Operation and Maintenance
ONE	National Observatory of Energy
p_{el}	Electricity price
p_{en}	Energy price
p_{FO}	Fuel oil price
p_{fuel}	Fuel price
PH	Process Heat
p_{NG}	Natural gas price
PP	Payback Period
PROSOL	PROgramm SOlaire
PTC	Parabolic Trough Collector
PV	Present Value
q_{sol}	Specific annual solar yield
Q_{sol}	Annual solar yield
Q_{usol}	Useful solar yield
RE	Renewable Energy
S_{fuel}	Fuel savings
SHIP	Solar Heat for Industrial Processes
SNDP	National Company for Oil
SPH	Solar Process Heat
SPP	Static Payback Period
STEG	Tunisian Company for Electricity and Gas
STIR	Tunisian Company of Refining Industry

T_a	Ambient temperature
T_i	Inlet temperature
TMM	Money Market Average
T_o	Outlet temperature
T_{op}	Operating temperature
TPES	Total Primary Energy Supply
TUN	Tunisia
UNEP	United Nations Environment Programme
UR	Utilization rate
VAT	Value added tax
VDI	German Engineering Association
WACC	Weighted Average Cost of Capital
η_0	Optical efficiency
η_{boil}	Boiler efficiency
η_{Col}	Collector efficiency
η_{sys}	System efficiency

1 Introduction

Since 1998 Tunisia cannot satisfy its increasing energy demands leading to a high structural deficit (World Bank, 2013). More than half of fossil fuels consumed in Tunisia must therefore be imported making Tunisia dependent on Algerian gas imports and global energy prices (MIEM, 2013a, p. 14). During the two politically unstable years after the revolution in 2011, rising global energy prices have not been passed to the consumers. As a result energy subsidies increased significantly and in 2012 they represented about one fifth of the state budget (MIEM, 2013b, p. 9), (budget law no. 2012-1). These subsidies impose a high financial burden on Tunisian public finances and impede other public investments.

In 2010, the final energy consumption of the Tunisian industry represented almost a third of the total final energy consumption in Tunisia. Three quarters of the industrial energy demand were used to generated process heat (PH) obtained exclusively by the combustion of highly subsidized fossil fuels (IEA, 2011).

While Tunisian fossil resources are decreasing, solar resources are promising throughout the country. Solar thermal applications for domestic purposes are already widespread make use of available solar energy (Baccouche, 2014, p. 1632). The high technical potential of solar heat for industrial processes (SHIP) was identified by Reiners (2011) and Amous (2013). The National Agency for Energy Conservation (ANME) recognized this potential already in 2010 by introducing the support program PROgramme SOlaire (PROSOL) Industrie. The program consists of a grant that covers 30% of the investment costs with a cap of about 65 EUR[1] per square meter of installed collectors (decree no. 2009-362). But until now, only two SHIP projects financed mostly by foreign funding have been reported.

Besides the fact that Tunisia is currently going through an insecure transition period impeding companies to invest into new technologies there are further financial barriers. In a first step the economics of SHIP investment will be assessed under current framework conditions. In a next step, the results of a sensitivity analysis allow to identify the largest financial barriers. To overcome the identified barriers, selected policy instruments are recommended. Throughout this work the following questions will be addressed:

- What concepts of SHIP exist and which industrial sectors are suitable?
- What are possible policy instruments to promote SHIP?
- What are the framework conditions in Tunisia?
- What are economics of SHIP investments under current framework conditions?
- Which factors influence the payback period (PP) of an investment in SHIP the most?
- What recommendations for future policy to promote SHIP in Tunisia can be derived?

[1] TND/EUR=2.32, exchange rate from July 15th 2014 used throughout this work, OANDA (2014)

2 Introduction to SHIP

This chapter will introduce the reader to the most common concepts of SHIP by giving an overview on relevant solar thermal collectors and by stating the different possibilities of solar heat integration into industrial processes. Furthermore, promising industrial sectors for the use of SHIP are identified and listed.

The worldwide database on SHIP installations (AEE INTEC, 2014) reported 132 solar thermal plants[2] providing SHIP with an installed capacity of almost 100 MW_{th} (see Figure 1). This number is relatively small compared to 234.6 GW_{th} of solar thermal capacity for domestic purposes (Weiss and Mauthner, 2013, p. 5). It shows that SHIP applications are not widespread yet, but the German Solar Industry Association (BSW) considers SHIP as essential for the further growth of solar thermal markets in the 2020s (Ebert et al., 2012, p. 10).

2.1 Solar Thermal Collectors

2.1.1 Fundamentals

Solar thermal collectors transform solar energy into thermal energy. Solar energy that reaches a horizontal area on the earth's surface is defined as global horizontal irradiation (GHI). It is comprised of two components, direct irradiation and diffuse irradiation. Direct irradiation comes directly from the sun, whereas diffuse irradiation is the non-directional part which is scattered by clouds and small particles in the atmosphere. Direct irradiation hitting a surface normal to sun beams is defined as direct normal irradiation (DNI) (Kalogirou, 2014, p. 95).

Depending on the type of solar thermal collector, either global irradiation or DNI is collected to provide solar heat. Two types of collectors can be distinguished: Stationary technologies, such as flat plate collectors (FPC) or evacuated tube collectors (ETC), collect direct and diffuse irradiation. As the name stationary suggests, they are installed and fixed at an optimal inclination angle (angle between horizontal surface and collector plane), which is about 31 °C in Tunis (PVGIS, 2012). Global irradiation on a tilted surface is G_{tilt}. The other type of technologies are concentrating solar collectors tracking the sun to collect DNI for example linear Fresnel reflectors (LFR) and parabolic trough collectors (PTC) (Kalogirou, 2014, pp. 125ff.).

Schemes of the mentioned collector technologies are shown in Figure 17 to Figure 20, p. 52 in the appendix.

When describing collectors, it has to be differentiated between various notations of areas. Sunlight enters first through the aperture area (1) and passes either directly to the absorber or it is reflected and concentrated onto an absorber. In case of stationary collectors, the aperture and absorber areas (2) are equal, whereas concentrating technologies reflect the sunlight from a large aperture area onto a small absorber area. The gross collector area (3) represents the actual size of a collector, including its frame.

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[2] According to Wolfgang Glatzl, AEE INTEC, there are definitely more realized SHIP plants worldwide, especially in India but the available data is little and too uncertain.

Throughout this work specific collector parameters, such as costs or efficiencies, relate to the aperture area. Furthermore, there is the size of the collector field (4), which includes the space between collector rows to avoid shading and allow access for maintenance (Heß and Oliva, 2010, p. 11).

2.1.2 Selection of Collector

As shown in Figure 1, more than three quarters of the reported SHIP plants use stationary collector technologies. This large share is partly owed to lower purchasing prices caused by high economies of scale due to high market penetration for solar water heating (Weiss et al., 2008, p. 11). It must be mentioned however that the high share of FPC is influenced by a large 27.5 MW plant in Chile which accounts for almost a third of the entire reported FPC capacity. Concentrating technologies account only for 10% which is probably due to the higher investment costs and less experience using these technologies for SHIP.

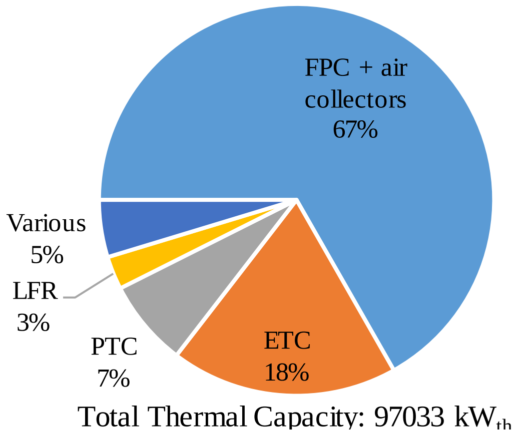

Figure 1: Solar Thermal Collectors Used in Reported SHIP Systems
Source: own illustration; AEE INTEC (2014)

Selecting the collector technology depends mainly on the collector costs, the temperature needs of industrial processes, and the characteristics of local solar irradiation. Further criteria, such as availability of technology or space for the collector field, may also influence the choice of the collector. Stationary collectors have economic benefits for lower operating temperatures, but as temperatures rise, the efficiency drops and the more costly concentrating technologies are used.

The collector efficiency η_{Col} depends on solar irradiation G, the ambient temperature T_a, and the operating or working temperature T_{op} of a collector. The latter in turn depends on the temperature level of the processes. In Tunis, solar irradiation ranges up to 950 W/m² during summer. Average ambient temperature throughout a year is about 20 °C, but during the day when solar systems are operating it increases correspondingly (El Ouderni et al., 2013, p. 165). The collector's operating temperature is the average of inlet temperature T_i and outlet temperature T_o, which is the temperature of the medium leaving the collector. Optical efficiency η_0 and heat loss coefficients c_1 and c_1 vary among different type of collectors and are determined empirically (Schweiger et al., 2001, p. 23).

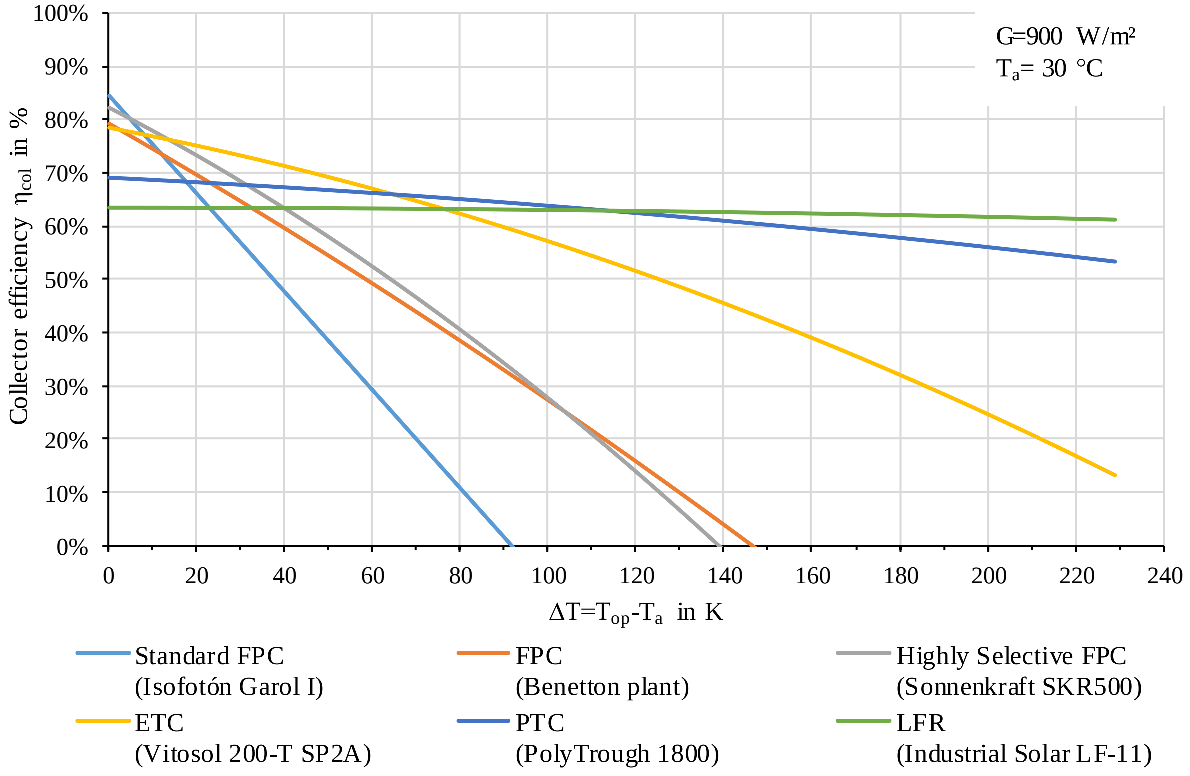

Figure 2: Efficiency Curves of Selected Collector Technologies

Source: own illustration; Schweiger et al. (2001, p. 24), Frein et al. (2014, p. 1162), Sonnenkraft (2014), Viessmann (2013), SPF (2013), Industrial Solar (2014)

$$\eta_{Col} = \eta_0 - (c_1 + c_2 * \Delta T)\frac{\Delta T}{G} \qquad \text{with } \Delta T = T_{op} - T_a \qquad (1)$$

Using the above equation, the efficiency curves of different collector technologies were plotted according to Tunisian climate conditions (see Figure 2). In Tunis, solar irradiation ranges up to 950 W/m² during summer. Average ambient temperature throughout the year is about 20 °C, but during the day when solar systems are operating it increases correspondingly and is therefore set at 30°C (El Ouderni et al., 2013, p. 165).

Due to the large absorber area of FPC, convective and radiation losses increase with rising operating temperatures. Standard FPC can only efficiently operate up to 80 °C. Highly selective FPC can be the most economical collector for temperatures up to 90 °C by coating the absorber with a selective layer[3] to reduce heat losses (Battisti et al., 2007, p. 51). ETC attain even higher efficiencies by creating a vacuum around the absorber tube to reduce convection and conduction losses. Increased efficiencies allow smaller collector fields in comparison to FPC fields with the same solar yield. This might be relevant when space is limited. In sunny countries, like Tunisia, concentrating technologies are used for operating temperatures roughly above 130 °C. The high efficiency at high working temperatures is owed to the small absorber area, which reduced heat losses significantly (Weiss et al., 2008, pp. 8ff.).

This study does not focus on one specific process or technology, but assesses the economics of the main collector technologies and processes that are within the corresponding temperature ranges, shown in

[3] The selective coating has high absorption values for shortwave solar radiation, but low emission values for longwave thermal radiation (Kalogirou 2004, pp. 242f.).

Table 1. FPC is chosen because of the existing experience with this technology for SHIP applications. Furthermore, advanced selective FPC are manufactured in Tunisia and the local market can be supported. Frein et al. (2014) designed the first SHIP plant in Tunisia for the textile company Benetton and the installed FPC were manufactured in Tunisia (see mail conversation in appendix Q, p. 80). ETC can provide PH at temperatures between FPC and concentrating technologies and are included to bridge the gap between the two technologies.

Tunisia has high DNI values offering favorable conditions for the application of concentrating technologies above process temperatures of around 130 °C. Since efficiencies of PTC and LFR are similar (see Figure 2), no differentiation will be made concerning the temperature range. Both technologies have certain advantages. PTC is the more developed technology due to experiences made with the electricity generation using PTC (Kalogirou, 2014, p. 144). LFR has the advantage that manufacturing of linear mirrors is cheaper than for parabolic mirrors (Xie et al., 2011, p. 2592). It does not require advanced technologies and could possibly be produced in Tunisia.

Collector type	**FPC**	**ETC**	**Concentrating** (PTC and LFR)
Costs	low	medium	high
Process temperature range in °C	40-80	80-130	130-250
Relevant irradiation	G_{tilt}	G_{tilt}	DNI

Table 1: Selected Collector Types and Characteristics
Source: own illustration

Besides the mentioned technologies there is a variety of other collector types and adaptations, especially for the temperature range between 80 and 120 °C. For this work, the types most widely used are considered to simplify the economic assessment. Therefore, the process temperature ranges are used as a reference for this work and not as fixed limits. Normally, every individual SHIP plant is carefully designed and the most economically and technically feasible collector is chosen among a variety of options.

2.2 System concepts

As SHIP is still in an early stage of maturity, there are no standardized concepts yet and each industrial process has to be analyzed beforehand to determine its feasibility (Battisti et al., 2007, p. 55). Various aspects have to be considered: required temperature levels, possible energy efficiency measures, operation mode of processes, and hydraulic integration into the existing heat distribution network (Schmitt et al., 2011a, p. 8).

The heat generated by collectors using solar energy is transferred to a fluid (e.g. water, thermo-oil, air). The heat-transfer fluid leaves the collector at respective outlet temperatures and transports the heat to the processes. Figure 21, p. 54, in the appendix shows various system concepts how heat is transferred from the collectors to the process. In open processes waste heat is not recovered (e.g. washing or cleaning) and the operating temperature of the collectors is lower, because cold make-up water leads to lower inlet temperatures (Lauterbach et al., 2011a, p. 4). Collector efficiencies are therefore higher than for closed processes with heat recovery that operate at higher working temperatures. Although this concept would yield the highest solar gains, waste heat recovery as an energy efficiency measure should be applied. Despite the higher inlet temperatures that lower collector efficiencies, the overall result is more favorable and solar process heat (SPH) can be provided at higher temperatures (Battisti et al., 2007, p. 52).

Heat exchangers are installed to transfer the heat from the collector medium to a different medium of the heat distribution system or of the process.

For a process with constant heat demand operating seven days a week, the system is designed in a way that the maximum daily solar yield is below the daily overall thermal load that can be supported with SPH. If solar yield is above the thermal load, energy would be wasted because it cannot be used. The solar system would be oversized and inefficient. Processes with such a high utilization rate are rare. But they are the most efficient and cost less, as generated SPH is always fed in and no storage-related costs incur. According to Battisti et al. (2007, p. 55) “most processes in smaller companies run for one or two shifts per day and show a batch[4] operation mode”. Therefore, storage tanks are usually installed to store solar yield during times without heat demand.

It is difficult to define a typical SHIP plant, because of the large variety of industrial processes. For the economic assessment a reference case will be assumed.

2.3 Solar Heat Integration

Whereas system concepts show possible ways to transfer heat from the collector to the process, solar heat integration addresses the question at which point solar heat is integrated.

Industrial companies usually generate heat in the form of hot water or steam with conventional boilers. Solar systems are usually retrofitted in existing heat systems and cannot substitute conventional boilers. They serve as a back-up and ensure reliable heat supplies at any time. The generated heat is fed into a heat distribution network supplying different processes with thermal energy. There are basically two possibilities to integrate solar heat in industrial processes: Either on the supply level by feeding solar heat into the heat distribution network or on the process level by providing a particular process directly with SPH (Schmitt et al., 2011a, p. 1).

2.3.1 Supply Level

PH is distributed by using either hot water or steam systems. Steam is more widespread in industrial companies, because of high levels of enthalpy released by condensing steam. As illustrated in Figure 3, solar heat can be integrated at two different points on the supply level. Either prior to the steam boiler by pre-heating feed water (1) or subsequently by generating steam parallel to the steam boiler (2). The advantage is that the integration of a solar system into an existing steam system is relatively easy. But the solar system has to provide heat at temperatures exceeding 100 °C, which requires high irradiation and usually the use of concentrating technologies (Schmitt et al., 2011a, pp. 3ff.).

[4] discontinuous

2.3.2 Process Level

The solar heat system is directly connected to one or more processes, see number (3) in Figure 3. Integration on the process level has the advantage that required temperatures are lower than on the supply level, because process temperatures are below the flow temperatures of the heat distribution network. This also allows the use of stationary collectors for low-temperature levels. On the other side the system design for the integration on process level can be complex, as shown by Frein et al. (2014) and Mauthner et al. (2013). For economic reasons Schmitt et al. (2011b) recommend this type of integration in Central Europe because solar irradiation is often not sufficient for attaining high temperatures required for integration on supply level.

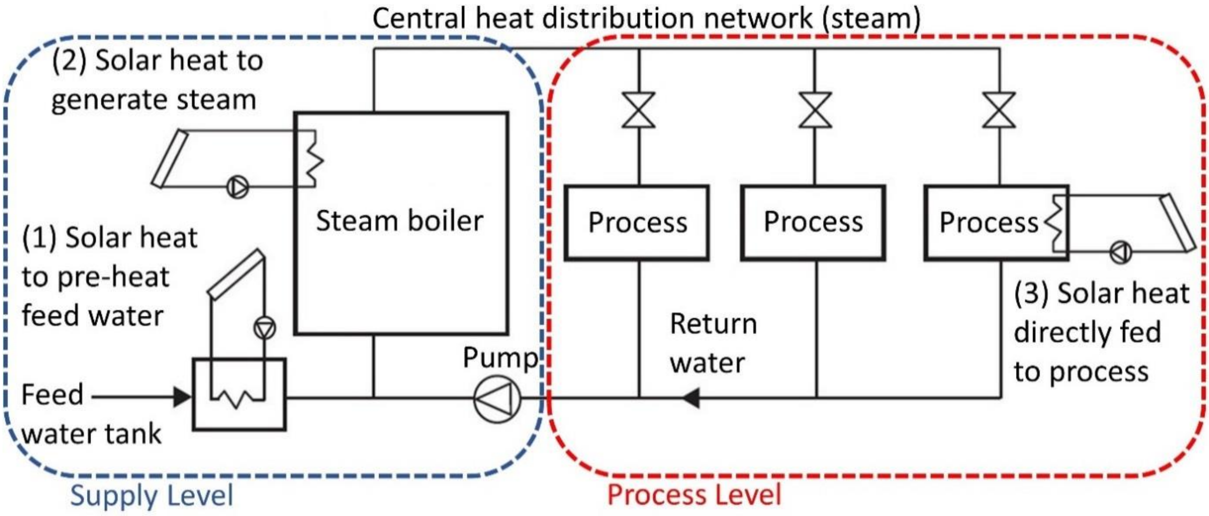

Figure 3: Possible Integration Points for SPH
Source: Kalogirou (2003), adapted by author

2.4 Suitable Industrial Sectors

As seen in section 2.1, current solar thermal collectors are capable of providing PH at low and medium temperatures ranging from 30 °C to 250 °C. Kalogirou (2003) reviewed literature on industrial processes that are suitable for the integration of SHIP based on constant heat requirements at low or medium temperatures. The identified processes and corresponding industries are shown in Table 20, p. 53 in appendix. Several studies have been conducted on the potential for the integration of SHIP in different European countries. The industry branches listed in Table 2 have been identified as promising and mentioned in at least in two studies.

The majority of reviewed studies considers the food, textile, chemical, and plastic industries the most promising industrial sectors for SHIP. This is primarily due to the high heat demand at low and medium temperatures of industrial processes, which can theoretically be provided by solar heat. Schweiger et al. (2001, p. 138) point out the importance of the paper industry because of its large heat demand, whereas Schnitzer et al. (2007, p. 1275) consider this high demand a barrier, because it requires solar thermal collectors that provide PH at medium temperatures. Thus, only concentrating collectors can be used. Whereas their efficiency is low in moderate climates of Central Europe due to little direct irradiation, they can be applied in Tunisia where direct irradiation is higher.

Industrial Sector	Literature
Food Processing (incl. beverages)	(Schweiger et al., 2001), (Kalogirou, 2003, p. 341), (Müller et al., 2004, p. 34), (Schnitzer et al., 2007, p. 1275), (ESTIF, 2006), (Vannoni et al., 2008, p. 6), (Lauterbach et al., 2011c)
Textiles	(Schweiger et al., 2001), (Kalogirou, 2003), (Müller et al., 2004), (Schnitzer et al., 2007), (ESTIF, 2006), (Vannoni et al., 2008), (Lauterbach et al., 2011c)
Chemical	(Schweiger et al., 2001), (Kalogirou, 2003), (Müller et al., 2004), (Schnitzer et al., 2007), (ESTIF, 2006), (Vannoni et al., 2008), (Lauterbach et al., 2011c)
Plastics	(Kalogirou, 2003), (Müller et al., 2004), (Schnitzer et al., 2007), (Vannoni et al., 2008), (Lauterbach et al., 2011c)
Paper	(Schweiger et al., 2001), (Kalogirou, 2003), (Lauterbach et al., 2011c)
Building materials	(Kalogirou, 2003), (Müller et al., 2004), (Schnitzer et al., 2007)
Automobile	(Schweiger et al., 2001), (Lauterbach et al., 2011c)
Metal treatment	(Vannoni et al., 2008), (Lauterbach et al., 2011c)

Table 2: Most Stated Industrial Sectors Suitable for SHIP
Source: own illustration

In addition to the reviewed literature, the database that contains 132 SHIP systems worldwide has been evaluated concerning the industrial sectors. Figure 4 shows the number of reported SHIP plants in each respective industrial sector. Sectors with less than four SHIP plants are not included. More than a third of SHIP systems are installed in the food sector (including beverages and dairy). The textile and leather industries (13%) seem to have promising conditions for the application of SHIP as well. The large number of reported projects favors future realizations within those sectors, because of gained experience and demonstrated feasibility. In the chemical industry only few systems have been reported, despite its large potential identified by reviewed studies. Also, only one company in the plastic industry is reported to makes use of solar heat and until now none in the paper industry obtain their high heat demand from solar energy.

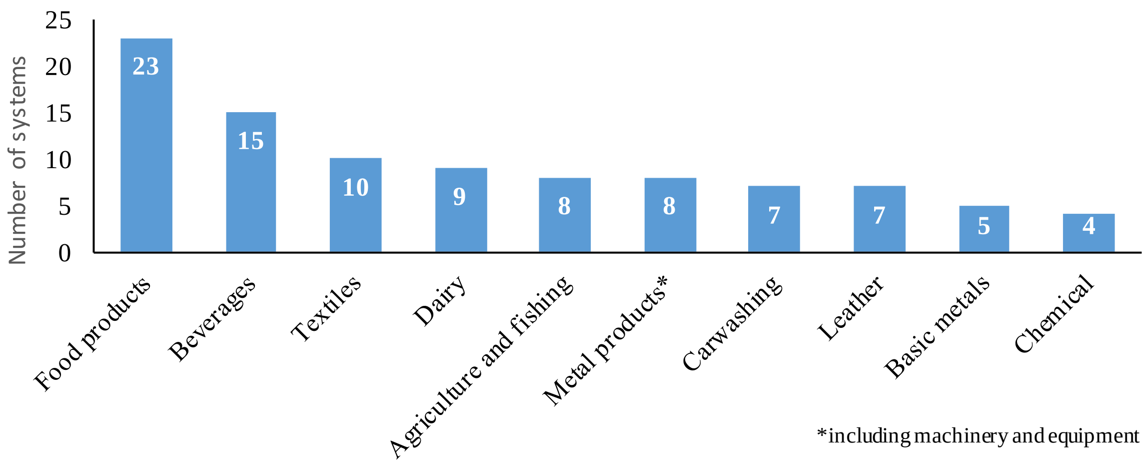

Figure 4: Most Common Industrial Sectors of Reported SHIP Plants
Source: own illustration, AEE INTEC (2014)

3 Policy Instruments

Renewable energy (RE) policies are usually comprised of different policy instruments aiming to support the growth of RE sources, reduce emissions, increase energy security, and stimulate technological progress and job creation. Instruments for solar thermal energy are less developed and often derived from experiences made in the renewable electricity sector (Connor et al., 2013, pp. 3f.). Since there is no literature on policy instruments specifically for SHIP, literature on renewable heat policy is reviewed. This chapter provides an overview of various instruments, some of which will be examined in chapter 5.5 for suitability in overcoming barriers to SHIP in Tunisia.

There is no well-established classification of policy instruments and among the reviewed literature categories differ (see Bürger et al. (2008), Connor et al. (2013), IEA (2004), Mauthner et al. (2014)). For this work instruments are grouped according to Connor et al. (2013) in financial and non-financial instruments.

3.1 Financial Instruments

The main barriers to the growth of SHIP are related to high investment costs and can be addressed by various financial instruments aiming to make solar heat more cost-competitive against conventional sources (Cottret, 2011, p. 52).

3.1.1 Grants

According to Ragwitz et al. (2005, pp. 39ff.) grants for investments in solar heat are the most popular policy instrument among European countries. There are three different forms of implementation: the incentive rate can be based on installed capacity (€/m^2 or €/MW), on a fixed percentage of total cost or on a fixed upper limit per installation. Combinations are also possible. To limit total costs affecting the state budget several countries cap the volume of subsidized capacity (Connor et al., 2013, p. 4). Grants have the advantages of low transaction costs[5], high acceptance among recipients and politicians, and a goal-oriented implementation (Bürger et al., 2008, p. 3157). Specific goals can be reached by adding funding conditions, for example, incentives are directed to specific technologies or to certified solar thermal components only (Connor et al., 2013, p. 4). On the other hand, grants impose a burden on state budgets and their availability depends on limited public funding. If the latter is exhausted and no further grants are issued, demand for the respective promoted technologies collapses. This fluctuating demand can lead to a stop-and-go development in the solar thermal sector and impede economic planning of production and investment for manufactures of solar thermal technologies (Bürger et al., 2008, p. 3157). To provide long-term, stable funding conditions continuity and sufficient funds are necessary (Stryi-Hipp et al., 2007, p. 72). Grants are usually applied for larger scale solar thermal installations using a technology in early stages of maturity when the number of installations and resulting total subsidies are still low (Foxon et al., 2005, p. 2132).

[5] Transaction costs are comprised of administrative costs, monitoring costs, legal costs and other costs arising from the implementation of a policy instrument.

3.1.2 Bonus Model

On the basis of the feed-in tariff system for the renewable electricity sector, the bonus model also provides the operator with a fixed remuneration (bonus) per kilowatt hour of generated thermal energy. But since there are no country-wide heating grids into which heat can be fed, the feed-in scheme used in the electricity sector is not applicable. The bonus is paid by the fuel supplier and the resulting additional costs are passed on to the fuel consumers and not to taxpayers. This independence from the state budget is the main advantage of the instrument because stop-and-go market developments can be avoided and planning reliability for operators is increased (Bürger et al., 2007, pp. 1ff.). Bürger et al. (2008, p. 3159) argue that the bonus model is superior to grants or use obligations. It has several advantages such as targeted allocation of financial support, reliable future cash inflows from investments, and lower risk surcharges and interest rates for bank loans because of guaranteed income. On the other hand, transaction and heat metering costs are high for small-scale generators. A further disadvantage is the low acceptance among stakeholders because the model is still unknown in the heat market. The bonus model is suitable for supporting solar thermal technologies that are not yet commercially deployable (Connor et al., 2013, pp. 9ff.).

To constrain the costs of the bonus model, bonus payments can be limited in time or to a certain amount of thermal energy generated. Furthermore, as investment costs for solar heat decrease in time the payment level should be adapted accordingly. The reduced payment is then provided to new operators, whereas old operators will still benefit from higher payments until they reach the total bonus limit. Another option to limit total costs is by capping the total subsidized capacity. But if the installed volume reaches the cap, it shows that bonus payments have been set too high and that lower payments would have achieved the same volume more economically. The level of the bonus could be linked to energy prices, although in times of high energy price volatility it is not recommended because unstable conditions decrease planning reliability and incentives to invest in solar thermal technologies (Connor et al., 2013, pp. 8f.).

3.1.3 Soft loans

Soft loans, also called concessional loans, are characterized by interest rates below the market rate. Advantages over grants are that costs are spread out over time, which is beneficial to the public budget. Soft loans are more attractive for large-scale solar thermal systems, like SHIP applications, since fixed bank and transaction costs are too high for small-scale applications. The adoption of soft loans can be challenging depending on whether governments are familiar with financing innovations and whether there are financial institutions such as state-owned banks. To create a financial framework for soft loans, governments must incentivize existing financial institutions to participate or create new ones. Further disadvantages are rising opportunity costs since public funds could be invested in projects that yield higher interests (Connor et al., 2013, pp. 10f.).

3.1.4 Levies

Levies in form of CO_2-taxes make carbon-emitting energy sources less attractive and provide additional tax revenues, which can be used to financially support solar thermal energy. The instrument is not favored among end user because of rising conventional energy prices. (Connor et al., 2013, pp. 10ff.).

3.1.5 Tax incentives

Three different types of tax incentives can be distinguished: Companies receive tax credits for installing eligible solar thermal technologies and can use them to cover tax bills (Connor et al., 2013, p. 10). Tax exemptions are another form of tax-related instrument and they lower investment costs of solar thermal technologies, for example through the abolition of the value added tax (VAT). A third taxation-based instrument is accelerated depreciation for eligible solar thermal technologies. Depreciations are income-reducing expenses leading to a tax advantage in early years because of reduced taxable income, in exchange for higher corporate income taxes in the following years. It encourages companies to acquire new assets (Azuela and Barroso, 2011, p. 41).

Acceptance depends on experience of governments with these kinds of instruments. Tax incentives are cost efficient and relatively easy to implement, but they lower tax revenues and burden taxpayers, not energy consumers. (Connor et al., 2013, pp. 10ff.).

3.1.6 Funding for Research, Development & Demonstration

Technologies like SHIP, which are still in an early stage of maturity, require public funding to support further research and development and the installation of pilot plants (IEA, 2007, p. 40). Decision makers in the industry tend to rely on conventional approved technologies rather than new solar heat technologies due to the high financial risk caused by interruptions of industrial processes. Demonstration plants will demonstrate the feasibility of SHIP and reduce doubts regarding reliability and functionality (Cottret, 2011, p. 26).

3.2 Non-financial instruments

Besides financial barriers, there are several barriers that cannot be overcome by providing financial incentives, and thus other non-financial instruments are used.

3.2.1 Education and Training

The "lack of specific skills of many designers and installers" presents a barrier to the widespread introduction of SHIP in the Mediterranean region, as identified by Cottret (2011, p. 52). Educational deficits can be tackled by offering training courses for installers and technicians, but also by introducing relevant study courses at university level, as has been done in Austria (see Egger, 2009, p. 44).

3.2.2 Awareness and Communication

A further barrier is low awareness of SHIP technologies among policy makers, installers, and industrial companies (Cottret, 2011, p. 52). Awareness-raising campaigns contribute to spread information about the potential of SHIP, the availability of financial support instruments, and training opportunities (Connor et al., 2013, p. 12). This instrument can be combined with financial ones to inform industrial companies about promising financial incentives.

3.2.3 Standardization and Certification

Bad performance of solar thermal components can create mistrust among investors and managers towards new technologies like SHIP and squander taxpayers' money. By introducing minimum standards, confidence in solar thermal products will increase and quality is assured. Only certified technologies should be eligible for financial support (Connor et al., 2013, p. 13). Stryi-Hipp et al. (2007, p. 74) stress that standards have to be set in collaboration with manufacturers to avoid that certain technologies are favored.

3.3 Energy Service Company

An instrument to overcome financing issues and the barrier of high upfront costs for industries investing in SHIP can be the promotion of Energy Service Companies (ESCO). The ESCO designs, installs, finances, operates, and maintains the SHIP plant. The industrial client buys SPH at a set price during the energy contract duration and provides the area for the collector field. There are only few examples of solar contracting. The "main barrier is the 'chicken-and-egg' problem" (ESV, 2011, p. 47), due to little awareness of this business model. The resulting lack of demand does not stimulate service companies and markets remain undeveloped.

ESCOs can be suppliers for solar thermal systems and therefore have the necessary know-how to operate and maintain a SHIP plant. Furthermore, they already have stronger ties with banks familiar with the technology and therefore better credit conditions (Buchinger et al., 2012, p. 1373). Yet, banks usually demand a high equity share due to elevated risk associated with the long-term investment (Mauthner et al., 2014, p. 75).

4 Framework Conditions in Tunisia

A thorough understanding of the present framework conditions in Tunisia is fundamental in order to assess the economics of SHIP and give recommendations for suitable policy instruments in Tunisia. A brief overview about Tunisia and the local energy market will be given. Furthermore, the potential for the application of SHIP in the Tunisian industry will be examined. In addition, relevant institutions will be presented, current legislation examined and the support program PROSOL will be described.

4.1 Country Overview

Tunisia is located in Northern Africa and is about half the size of Germany. It borders the Mediterranean Sea in the north, Algeria in the west and Libya in the east. It has population of 10.9 million people of which about 800,000 live in Tunis, the capital. The Mediterranean climate is hot and dry in summers, while winters in the north are rainy and mild, offering fertile land for agriculture. By contrast, the desert in the south stays arid (CIA, 2014).

After independence from the French occupation in 1956, two presidents ruled the country until discontent among the population led to the revolution 14th of January 2011. In October, elections were held for the National Constituent Assembly and by the end of 2011, Moncef Marzouki became the new president. The task of the Assembly was to draft a new constitution and, after its ratification in January 2014, the political situation became more stable. The next presidential and parliamentary elections are being prepared and will be held by the end of this year (CIA, 2014).

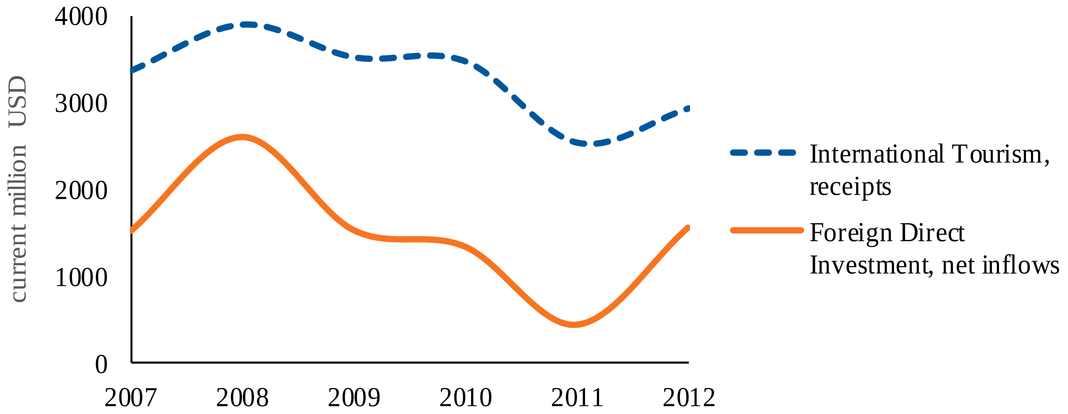

Figure 5: Income from Tourism and Foreign Direct Investment; Tunisia, 2007-2012
Source: own illustration; World Bank (2013)

As can be seen in Figure 5, income from tourism and foreign direct investments[6] have dropped by around a quarter in 2011, substantially weakening the country's economy. Meanwhile, foreign investments have regained an even a higher level as prior to the revolution. Apparently, investors outside of Tunisia have confidence in this young democracy, although sovereign credits have been downgraded four times after 2011. This left Tunisia with a Ba3 rating ("substantial credit risk") (Moodys, 2014). The economy is slowly recovering from the impacts of the revolution, but problems such as high inflation, corruption,

[6] Net inflows from foreign direct investment is new investment less disinvestment of foreign investors in local companies. It can be seen as an indicator for the economic attractiveness of a country.

high unemployment among the youth (42%), and the less developed inland remain challenging during the transition period (CIA, 2014).

The past ten years the average annual inflation rate was around 4%, currently it is at about 6% and in the future it is expected to decrease gradually as shown in Table 3.

	2004-2013	August 2014	2015-2034
Annual inflation rate in %	4.16	6.07	4.39%

Table 3: Annual Average Inflation Rates; Tunisia 2004-2034
Source: World Bank (2013), Trading Economics (2014), see Table 23 for calculation

In 2013, Tunisia's gross domestic product (GDP) per capita was 4,329 USD, about a tenth of Germany's. 9% of the GDP was generated in agriculture, 29% in the industry, and 62% in the service sector. About a third of Tunisia's labor force works in industry mainly in coastal towns like Tunis, Sousse, Sfax or Gabes (World Bank, 2013). Main exports are textiles, agricultural products, phosphates and chemicals, and petroleum products. More than a quarter of exports go to France (CIA, 2014).

4.2 Energy Situation

As can be seen in Figure 6, the economic growth during the last 20 years is accompanied by an increase in Total Primary Energy Supply (TPES), which is the total consumption of primary energy. It shows, that decoupling economic growth and energy consumption is a difficult task. Nonetheless, as GDP growth exceeds the rise of TPES, Tunisia's energy intensity[7] is declining and below the mean energy intensity of Middle Eastern countries (IEA, 2013, p. 235).

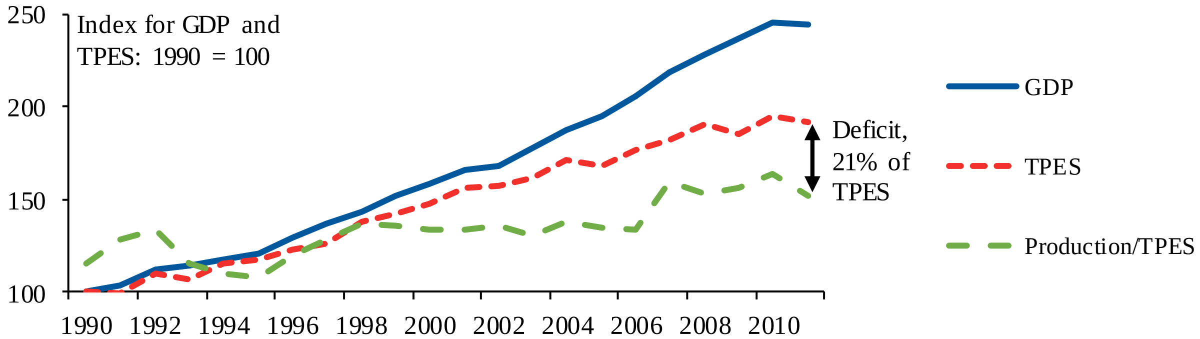

Figure 6: Comparison GDP, TPES and Total Energy Production; Tunisia, 1990-2011
Source: World Bank (2013)

Unlike Algeria or Libya, Tunisia does not have large oil or gas resources. Tunisia has not been able to satisfy its increasing primary energy demand since 1998. This has led to a structural deficit of the Tunisian energy balance (see Figure 6). This represented about one fifth of the TPES and, according to the Tunisian National Agency for Energy Conservation (ANME, 2013, p. 7), it could rise up to 60% by 2030. It makes Tunisia especially dependent on Algerian gas imports and global energy prices. For further information about the Tunisian energy balance, see Table 22, p. 56 in appendix.

[7] The International Energy Agency IEA (2013) defines energy intensity "as primary energy demand per unit of economic output" and is used to compare energy efficiencies of different countries. It is easy to calculate and no detailed data is necessary, but the validity is questionable because energy efficiency is also influenced by the economic structure and the climate of each country.

4.2.1 Industrial Energy Demand

Total final energy consumption of the industry accounts for more than a quarter of the total final consumption (see Figure 7). As a result of the constantly growing Tunisian industry (World Bank, 2013), it can be expected that industrial energy demand will further increase in the future. More than three quarters of the industrial final energy demand were obtained by the combustion of fossil fuels, the remaining quarter accounted for electricity consumption. Space heating and sanitary hot water play a minor role in Tunisian industries, due to the mild climate, therefore it can be assumed that the industrial consumption of fossil fuels is almost exclusively used to generate PH. This heat was obtained using mainly natural gas (NG), petroleum coke, and fuel oil (FO) (see Figure 7). A more detailed distribution of the industrial heat demand is shown in Figure 12, p. 20.

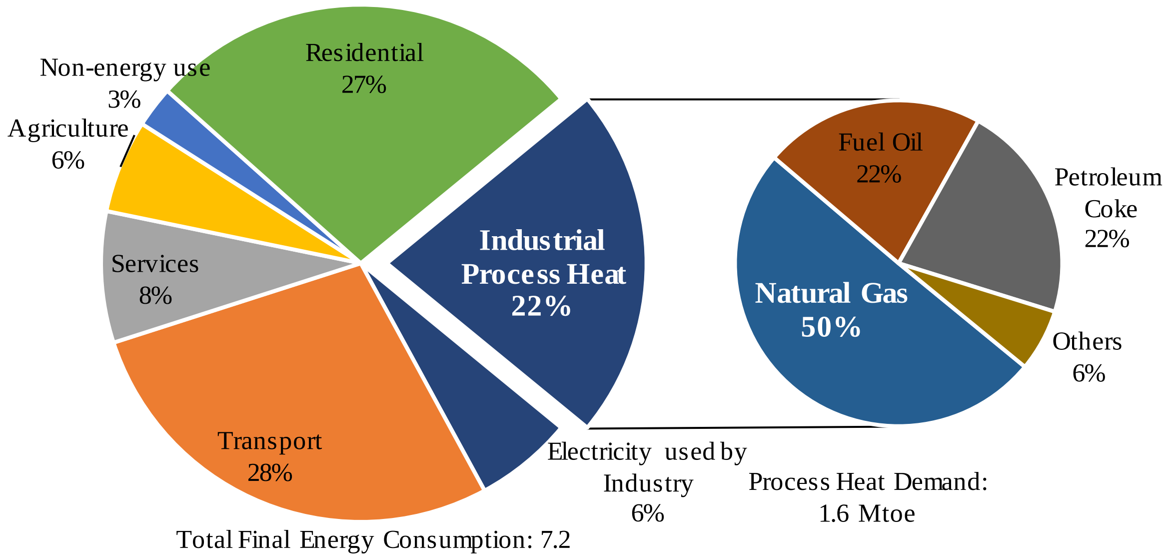

Figure 7: Total Final Energy Consumption by Sector and Industrial PH by Fuel Type; Tunisia, 2010
Source: IEA (2011), ONE

In the following a closer look will be taken on the NG market, because it is the most deployed combustible in Tunisian industries.

4.2.2 Energy Prices, Subsidies, and Trends

Industries have to pay VAT for energy like end customers, that is, there is no pre-tax deduction for energy taxes (see expert interview with Ali Ben Hmid in appendix P, p. 79). The following energy prices include therefore the VAT. Energy prices are set and adjusted by the Ministry of Industry, Energy, and Mines (MIEM).

SHIP plants do not consume fossil energy, but small amounts of electrical energy. Electricity prices for industries at medium voltage vary depending on time of day. The expected price for electricity consumed by the solar system is shown in Table 4.

	Electricity	Fuel Oil	Natural Gas
Prices in EUR cents/kWh (incl. VAT)	8.19	2.28	1.63

Table 4: Energy Prices for Industries
Source: see Table 24, Table 25, and Table 26 in appendix for sources and details on calculation

Integrating SHIP will partially substitute the use of NG and FO. The resulting fuel cost savings depend on the price of the combustible. Prices for NG are graded by pressure level (medium or high) and level of consumption. High pressure is only consumed by power plants and heavy industries with high heat demands at high temperature levels (see expert interview with Ali Ben Hmid in appendix P, p. 79). This implies the use of waste heat for low or medium temperature processes and no need for SHIP. The average retail price for industries suitable for SHIP amounts currently to 1.63 EUR cents/kWh incl. VAT. In Germany the mean retail price of NG for industrial customers in 2013 was 4.68 EUR cents/kWh incl. taxes, which is almost three times as high (BNetzA, 2013, p. 243).

The main reason for low NG prices are high subsidies for the energy sector. As illustrated in Figure 8, direct energy subsidies have increased significantly during the last three years after the revolution. Until the adoption of the new constitution in January 2014, Tunisia was going through a difficult political crisis and discontent among the population was growing. Import prices for Algerian NG more than doubled between 2009 and 2012. But to assure price stability and ease the growing costs of living due to high inflation, the raising prices were not passed directly to the consumers (see Figure 8). Instead, the gap was bridged by additional energy subsidies. They impose a high financial burden on Tunisian public finances and impede other public investments.

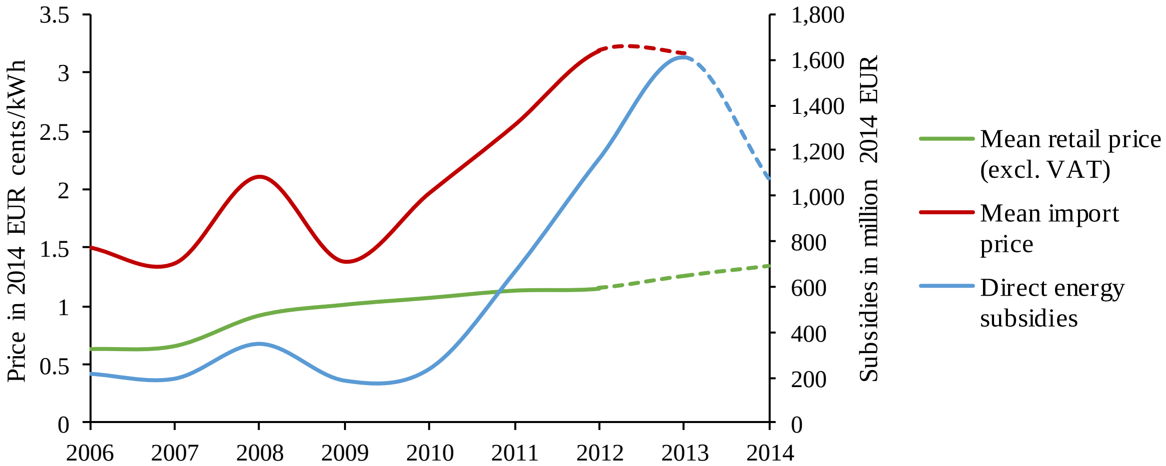

Figure 8: Mean Retail and Import Prices for NG, Direct Energy Subsidies; Tunisia 2006 – 2014
Source: ONE, MIEM (2013b, p. 9), Laws no. 2013-51 and 2013-54, STEG (2014d, 2014e)

In 2014, the political situation became more stable and direct energy subsidies were reduced according to the budget law 2013-54. In the past, however, budgets acts have been amended at the end of each year. In 2013, for instance, the updated direct energy subsidies were considerably higher than originally foreseen. It shows the willingness of the government or rather the Ministry of Finance to reform the energy sector and lower the burden of energy subsidies on the state budget. Concrete action has already been taken by the MIEM in January and May 2014 when NG prices were raised twice by 10%. The reduced subsidies for NG will save the Tunisian state 0.2% of the GDP and future energy price increases are planned by the government (IMF, 2014, p. 16).

In 2012, direct subsidies amounted to more than 1.1 billion EUR, but, as shown Figure 9 this sum rises to around 2.3 billion EUR when indirect subsidies are also taken into account (see section 4.4.1 for origins of indirect subsidies). This amount represents around one fifth of the state budget in 2012, which is fixed in budget act no. 2012-1. More than half of total energy subsidies were used to subsidize NG, given that electricity is based almost solely generated using NG (see Table 21, p. 55 in appendix).

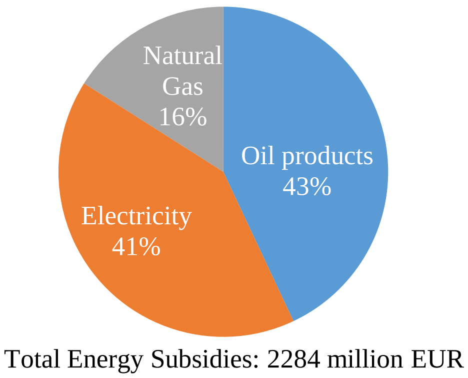

Figure 9: Direct and Indirect Energy Subsidies by Type of Energy; Tunisia, 2012
Source: MIEM (2013a)

Figure 10 shows that in 2012 the total costs for the provision of NG were almost 3.1 EUR cents/kWh. The same year, two thirds of NG at medium pressure, which is used by industries suitable for SHIP, were subsidized. In other words, the state paid an additional sum around twice as a high as the industrial consumers' NG bill, almost 2 EUR cents/kWh. The mean cost price has probably not altered significantly since 2012, as import prices of Algerian NG are estimated to remain relatively stable since 2012 (see Figure 8). By subtracting the present industrial retail price of 1.38 EUR cents/kWh (excl. VAT) from the cost price, it can be assumed that total subsidies for NG consumed by industries suitable for SHIP amount to approx. 1.7 EUR cents/kWh. Hence, the Tunisian state would save this sum for each kWh of non-burned NG. FO is also subsidized by two thirds, according to the MIEM (2013b, p. 15) and only consumed by industries.

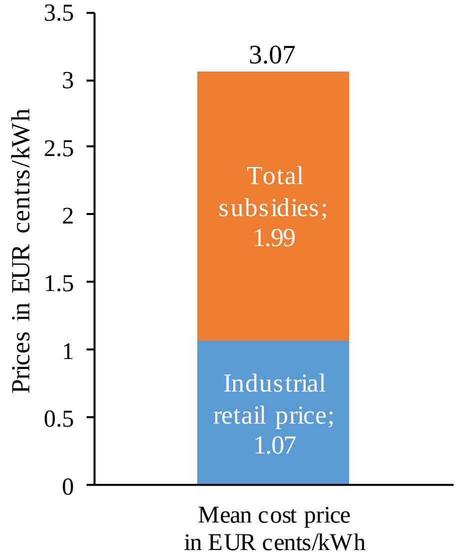

Figure 10: NG: Mean Cost Price, Industrial Retail Price, and Total Subsidies; Tunisia, 2012
Source: (MIEM, 2013a), MIEM (2013b, p. 15)

As stated before all energy prices are set by the MIEM and future trends depend therefore on future energy policy. In the past eight years, NG retail prices increased on average by about 10% (see Table 27, p. 59, in appendix). In 2008, the MIEM adjusted NG prices by 40% due to the oil price shock. Since

2011, there have been no major price increases, causing the sharp rise in energy subsidies (see Figure 8). To reduce those subsidies, the government has to start passing at the least increasing import prices of NG to the customers. In addition to the import prices, energy subsidies are planned to be reduced within the next six years, according to the International Monetary Funds (IMF, 2014, p. 15). In January and May 2014, NG and electricity prices have been adjusted twice by 10%, resulting in a total increase of 21%. During the next six years, these prices are assumed to increase at an average annual rate of 10%, similar to the past eight years and reasonable if the government plans to reduce energy subsidies. Considering this rate, energy subsidies will have been reduced by 2021 and for the following years, lower price increases are expected. However, they will still increase at a higher level than import price, considering that import prices are currently more than twice as high as retail prices of NG.

As electricity is almost exclusively generated using NG, electricity prices are assumed to increase at the same rate as NG prices. Furthermore, experience shows that electricity prices have been increased simultaneously with NG prices at similar rates (see expert interview with Ali Ben Hmid in appendix P, p. 79).

Prices of FO have increased by an annual rate of 8.5% the last eight years (see Table 27, p. 59, in appendix). FO prices are linked to the global price of crude oil, which is expected to rise at slightly higher rates than NG during the next 20 years. It is also strongly subsidized (MIEM, 2013b, p. 15), therefore it is assumed that prices will increase at similar rates.

The assumed annual energy price increases are shown in Table 5.

	2015-21	2021-35	Source
European import price increase **NG**	0.21%	0.43%	WEO 2013
Tunisian price increase **NG**	2.25%	0.72%	Wuppertal Institute
Import price increase **crude oil**	0.45%	0.83%	WEO 2013
Tunisian price increase **crude oil**	1.10%	1.00%	Wuppertal Institute
Estimated annual retail price increase of NG, Electricity, and FO	**10.00%**	**5.00%**	Estimated increase considering historic data, import price increase and energy subsidy reductions

Table 5: Estimated Annual Energy Price Increases; Tunisia 2015-2035

Source: IEA (2013), see Table 29 in appendix for details

Calderoni et al. (2012, p. 1394) assume a yearly increase of Tunisian energy prices at 6%. But this assumption holds for the next 20 years and is based on a reference published prior to the revolution. The two years afterwards, energy prices have not been increased, therefore energy price increases above 6% within the next six years can be expected.

4.3 Potential for SHIP

Examining the potential for SPH in the Tunisian industry is of major importance. Only if potential for the application of SHIP exist, can efforts to promote this technology with public finance be justified.

4.3.1 Solar Irradiation

Using the high solar irradiation in Tunisia for SPH can contribute to lower the industrial consumption of subsidized NG and in doing so ease the strain on public resources in the future.

As can be seen in Figure 11, GHI ranges from 1800 in the northern part to 1900 kWh/m²/a in the central part of Tunisia. The southern part is not of interest, because no important industries are located in this region. DNI values are within 1900 and 2100 kWh/m² per year.

Despite promising irradiation, RE sources still play a minor role in Tunisia: They make up only 1% of the electricity mix (see Table 21, p. 55 in appendix), but ambitious goals to increase their share up to 30% by 2030, mainly through wind energy and photovoltaics, are set (ANME, 2013, p. 6). In the heat sector solar water heating for domestic purposes has experienced strong growth (see Figure 13, p. 24). By contrast, there are still no installations using solar thermal energy for industrial processes.

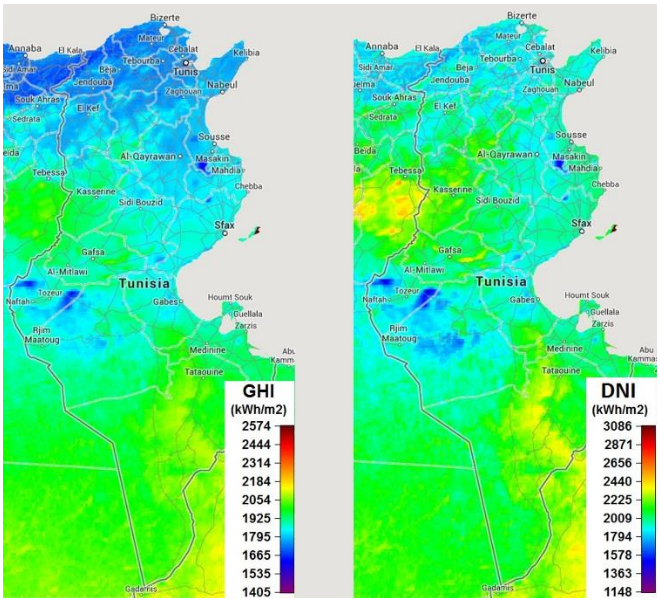

Figure 11: Annual Global Horizontal Irradiation and Direct Normal Irradiation; Tunisia
Source: (Solar Med Atlas, 2010)

4.3.2 Suitable Industrial Sectors

There is no data on the distribution of temperature levels for different industrial sectors in Tunisia, but it is assumed that the respective sectors use similar processes and are therefore also applicable for the integration of SPH. Figure 12 shows the heat demand of different industrial sectors in Tunisia. As mentioned before, the main combustibles are NG, petroleum coke and FO. The latter is a combustible used by industries in rural areas that are not connected to the NG grid. They have potential for SHIP, because prices for FO are higher than for NG, resulting in higher energy savings using SPH. Petroleum coke is used only for cement making, an industry requiring high process temperature levels and therefore not suitable for the integration of SHIP.

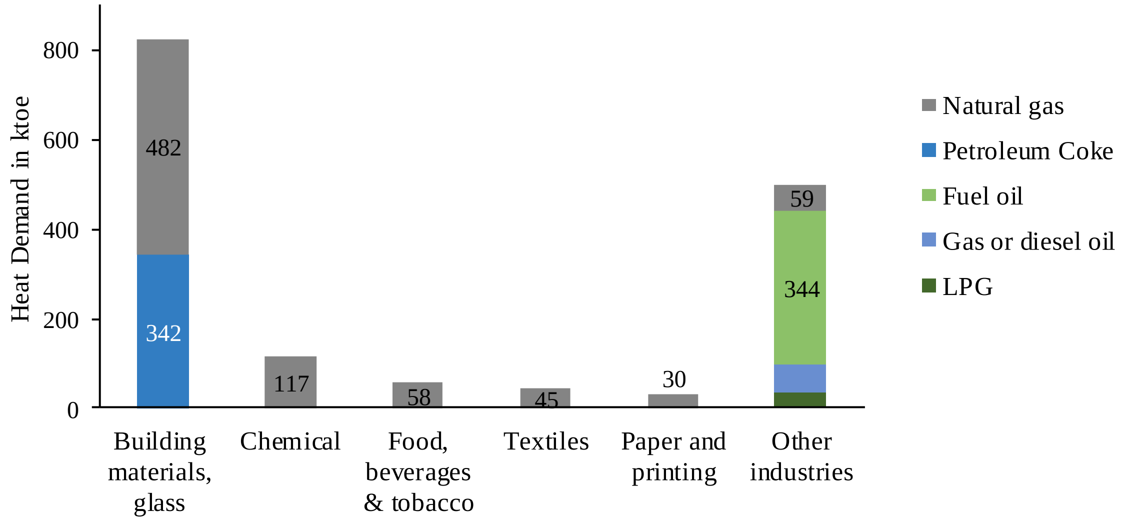

Figure 12: Heat Demand of Tunisian Industry Sectors by Fuel Type
Source. own illustration, ONE

Taking into account the most suitable sectors for SHIP identified in section 2.4, shows that several promising industrial sectors with respective heat demands exist in Tunisia. Chemical, food, beverages and tobacco, and textiles industries are among the most promising sectors. Paper and brick-making are also suitable.

4.3.3 Theoretical and Technical Potential

Reiners (2011) analyzed the potential of solar steam generation in the Mediterranean region. He took into account industrial sectors with processes at temperatures below 250 °C and calculated their energy demand using specific energy indicators. Using the estimated energy demand and the share of PH derived from findings of previous studies the amount of PH was estimated. Furthermore, he considered the implementation of energy efficiency measures prior to the SHIP integration, which reduced the PH demand by 20%. Finally, he estimated the yearly theoretical potential for SHIP to be around 375 ktoe in Tunisia.

Amous (2013) focused in his study on the potential of SHIP in Tunisia only applying a bottom-up approach. The results of 64 case studies were extrapolated on the entire Tunisian industry to determine the demand for hot water and steam below 250 °C. He estimated the theoretical potential for SHIP in Tunisia to be around 320 ktoe per year. In addition, he used a simulation tool to determine the annual technical potential of 32 ktoe by taking into account further aspects/constraints such as yearly demand profile (hourly heat flow rates, operating temperatures, return temperatures of working fluids), restrictions on available collector area, solar irradiation, and collector specifications.

Both studies come along with some uncertainties. The specific energy indicators used by Reiners were based on a small sample of German and Austrian companies, which implies that energy demand of Tunisian industries might be underestimated because of less energy efficient processes. Moreover, he used projections to estimate missing data for the Tunisian industry by transferring it from another country where data was available. Amous did not consider energy efficiency measures, despite the elevated energy intensity in Tunisia, resulting in overestimated PH demands. On the other hand, the potential was rather underestimated, because industrial processes operating with hot air as a working fluid were not considered. The promising potential of Tunisian brick-making industry for instance, which uses hot air to dry the bricks (Schnitzer et al., 2007, p. 1275), was left out.

Due to different methodologies and the mentioned uncertainties, the results of both studies differ and the theoretical potential estimated by Amous is about 15% lower than Reiners' estimation.

Theoretical potential Industrial heat <250 °C in ktoe/a	Technical potential Solar heat in ktoe/a (GWh/a)	Solar fraction in %	Source (Country)
11178.99	1341.36 (15,600)	3.1	Lauterbach et al., 2011 (Germany)
376.61	n/a	n/a	Reiners, 2011 (Tunisia)
318.92	31.89 (370)	2.0	Amous, 2013 (Tunisia)

Table 6: Estimated Potential for SHIP in Germany and Tunisia

Source: own illustration; Lauterbach et al. (2011b), Reiners (2011), Amous (2013), for details see Table 31 and Table 32, p. 62 in appendix

The scientific quality of Amous' study is questionable, because of lack of references which raises questions on origins of information. However, the applied bottom-up approach to estimate the potential was also used by the study on the potential for SHIP in Spain and Portugal (Schweiger et al., 2001), which is well-known (cited 27 times according to google scholar) and one of numerous publications of co-author K. Hennecke. Comparing the technical potential of Amous' study with other studies is limited, because different temperature levels and industrial sectors were considered (see Table 32, p. 63 in appendix). Still, similar relative technical potentials were estimated by Lauterbach et al. (2011b). According to Amous, the potential solar fraction[8] is 2% in Tunisia, which is little when comparing it with Germany with an estimated solar fraction of around 3.1% (see Table 6). The main reason for the higher solar fraction in Germany is probably the large heat demand for space heating and domestic hot water. It represents more than a third of the solar heat in Germany (Lauterbach et al., 2011b, p. 4) and is negligible for Tunisia. All in all, in can be concluded, that the estimated potential for solar heat in Tunisia is comprehensible. Important aspects, such as energy efficiency measures or hot air as a working fluid, were not considered. However, it cannot be determined whether underestimation or overestimation predominates.

The market volume for solar thermal application is estimated at around 150 million EUR by Amous (2013). Besides, the Tunisian state could save up to 6.5 million EUR per year, when taking into account the omitted subsidies for NG.

4.4 Institutional and Regulatory Framework

The successful implementation of policy instruments for the promotion of SHIP requires well-established institutions and a legislative framework. In the following the main institutions and legislation concerning the solar thermal sector in Tunisia will be described.

[8] useful solar heat divided by the total industrial heat demand

4.4.1 Institutions

The *General Direction of Energy* (DGE) is one of the departments of the *Ministry of Industry, Energy, and Mines* (MIEM) and in charge of the administration of the energy sector. In the following relevant institutions of the Tunisian energy sector, which are under the direction of the DGE, are listed:

The *National Observatory of Energy* (ONE) is responsible for the collection and processing of energy data and the publishing of energy reports. The *National Agency for Energy Conservation* (ANME) was founded in 1985 to apply the nation's energy policies. It implements projects and support programs concerning energy efficiency and the promotion of RE (see also 4.4.2). The *Tunisian Company for Electricity and Gas* (STEG) is basically the only producer of electricity (see Table 21, p. 55 in appendix), because it was only until 1996 that independent power producers obtained the right to produce electricity and sell it to the STEG. For transmission and distribution of electricity and NG the STEG is still monopolist. The state-owned company reported a loss of 7.4 million EUR in 2011 (STEG, 2011, p. 62), and has additionally a high amount of unpaid receivables in form of electricity and NG bills, which were estimated to have reached around 232 million EUR in January 2014 (African Manager, 2014). The *STEG RE* was founded in 2009 to provide services for the STEG for RE projects, ranging from feasibility studies to realizations. The state-owned *Tunisian Company for Oil Activities* (ETAP) administrates oil and gas explorations and reported profits at around 233.8 million EUR in 2012 (ETAP, 2013, p. 78), (Lechtenböhmer et al., 2012, p. 111-112).

For more detail on institutions and their organizational structure, see Figure 22, p. 64 in appendix.

The ETAP imports Algerian NG and sells it to the STEG. The MIEM fixed this price at around 0.34 EUR cents/kWh (RCREEE, 2010, p. 8), whereas in 2012 the ETAP paid about ten-fold as much to the Algerian gas exporter, according to ETAP's annual report (ETAP, 2013, p. 62). The ETAP generates profit through extraction fees paid by foreign oil producers and from the export of crude oil. Those profits are used to bridge the gap between import prices for NG and the low price paid by the STEG. This is one form of indirect subsidies for NG and electricity generated mainly with NG (see expert interview with Afef Chachi Tayari, in appendix P, p. 79)

4.4.2 Legislation

Decree no. 95-744 (April 24th 1995): tax exemptions for RE products

Article 6, section 5 grants exemptions of VAT and reduces customs duties to 10% for RE products.

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

Article 2 specifies the three objectives of Tunisian energy policy: energy efficiency, promotion of RE, and substitution of conventional energy. Article 14 regularizes the implementation of a national support program focused on four different RES among solar thermal energy. Article 17 lists the major activities and functions of the ANME, such as the administration of industrial energy audits, realizations and monitoring of demonstration projects, capacity building, and the proposal of policy instruments. The latter also includes non-financial instruments, e.g. education and awareness raising. Energy audits are periodic and obligatory for industries with an annual consumption above 9,300 MWh (RCREEE, 2010, p. 106)

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

The resources for financial policy instruments come from a levy on cars in the tourism sector (Art. 1) and from a levy on air conditioners (Art. 2).

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

The *Funds for Energy Transition* (FTE) (before 2013: FNME) was created by article 12. It was founded to finance energy efficiency measures, the promotion of RES, and the substitution of conventional energy. The financial resources of the FTE derive from the levies fixed by law no. 2005-82 plus grants from foreign aid. The budget amounts to 43.1 million EUR in 2014 (law no. 2013-54). The FTE is managed by the ANME.

Law no. 2009-7 (February 9th 2009): modifying law no. 2004-72

Article 7 entitles industrial companies to operate combined heat and power (CHP) installations. They obtain the right to generate their own electricity, to use the STEG-owned grid for transport and to sell excess electricity to the STEG (max. 30% of annual generation according to decree no. 2009-2773, Art. 1). Direct investment incentives for CHP are fixed at 20% of investment cost, capped at 215,500 EUR (decree no. 2009-362, Art. 1 (8)). Amous (2013, p. 17) pointed out that the promotion of CHP can be seen as a rival to SHIP, due to short pay back periods between four and six years.

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

Article 1 sets direct investment incentives. Relevant sections for RE projects in the industry are listed in Table 7

Section no.	Concerning	Incentive rate	Cap in TND (EUR)
1	Energy audits	70% of costs	30,000 (approx. 13,000)
2	Demonstration projects	50% of total costs	100,000 (approx. 43,000)
3 a)	Investments in RE	100% of immaterial costs (e.g. feasibility studies, design, etc.)	70,000 (approx. 30,000)
6 a)	Substitution of NG in industries	20% of costs for installations	400,000 (approx. 172,400)
7 a)	Solar process heat	30% of investment costs	150 TND/m² (64.66 EUR/m²)

Table 7: Investment Incentives for RE in the Tunisian Industry
Source: Decree no. 2009-362, Article 1

4.5 Support Program PROSOL

A closer view at the current support program PROSOL allows to find out what policy instruments were already applied by Tunisian institutions, which experiences were made in the solar heat sector, and what support mechanisms for SHIP currently exist.

4.5.1 Implementation and Policy Instruments

The mentioned laws are part of the regulatory framework for the support program Programme Solaire (PROSOL). PROSOL Residential was introduced in 2005 in cooperation of the MIEM, the ANME and the United Nations Environment Programme (UNEP). Besides, the Italian-led Reneweable Energy Centre (MEDREC) provided financial support. It was aimed to promote solar water heating for domestic use in Tunisia by involving private banks to provide credits covering investments costs. After its success a new concept was launched in 2007 and expanded to the services sector, called PROSOL Tertiary (Trabacchi et al., 2012, p. 3-6).

The following policy instruments have been used throughout PROSOL:

- Grants: From 2005-2009 a fixed percentage of capital costs (20%), since then based on installed collector area. For certified technologies only. Funded through MEDREC and FNME (Trabacchi et al., 2012, p. 3, 6).
- Soft loans gradually phased out during the first years of PROSOL: First 12 months 0%, previous six months 4%, last six months regular interest rate of 7%. Interest rate subsidy funded by MEDREC. (Menichetti and Touhami, 2007, p. 3). In the second concept of PROSOL interest rates of private banks are about 6.1% (Trabacchi et al., 2012, p. 10).
- Tax incentives: VAT exemption and custom duties reduction for RE products (decree no. 95-744)
- Non-financial instruments: awareness campaigns targeted at consumers and private banks, education and training for suppliers and commercial banks, and certification of solar thermal components ("QUALISOL") (Trabacchi et al., 2012, p. 3).

4.5.2 Outcome and Success Factors

As illustrated in Figure 13, around 63,000 m² of collector area has been installed per year after the implementation of PROSOL up until 2012. This is nine times more than before the launch of the support program. Furthermore, the number of suppliers rose from eight (incl. one local) to currently 45 (incl. eight local). The eight local manufactures produced 70% of installed solar water heaters together with international partners allowing technology transfer. Besides, the number of approved installers and certified models rose significantly and 3,000 jobs have been created (Baccouche, 2014, pp. 1632f.).

In addition, financial instruments reduced levelized costs of energy and PP. Energy savings are estimated at 250 ktoe over the lifetime of solar water heats, resulting in the reduction of energy subsidy and CO_2 emissions (Trabacchi et al., 2012, p. 14).

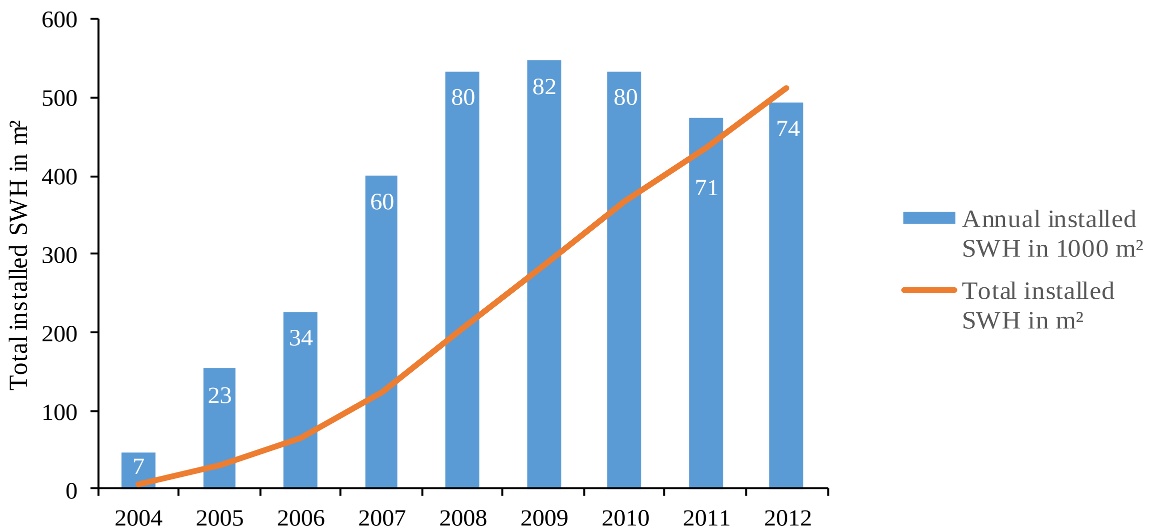

Figure 13: Installed Solar Water Heaters; Tunisia, 2004-2012
Source: Baccouche (2014, p. 1632)

Menichetti and Touhami (2007, p. 3) argue that the success is mainly owed to the creation of a credit-market for solar water heaters by engaging local banks and involving the STEG. Interest rates and loan duration of private banks for similar loan products usually amount to 14% over three years. Their willingness to offer loans at 7% for a duration of five years is due to the innovative loan repayment of households through the STEG's electricity bill. The STEG enforces and guarantees loan payments, resulting in reduced credit risks. Trabacchi et al. (2012, p. 9) estimate that between 2005 and 2010 82% of total investment (approx. 100 million EUR[9]) were provided by credits from the commercial finance sector. Another success factor is the institutional support, especially on the part of the ANME, awareness raising campaign, and the comprehension of relevant stakeholders (Trabacchi et al., 2012, p. 27).

4.5.3 PROSOL Industry

After the success of PROSOL Residential, the support program was extended in 2010 to promote SPH for the Tunisian industry. Together with the Italian Ministry for the Environment, Land and Sea (IMELS) and UNEP the program aimed to install 30,000 m² of collector area providing SPH. It is regarded as a pilot phase to identify barriers and suitable policy instruments and to install demonstration plants (Baccouche, 2014, p. 1631). Currently, there are two SHIP projects in Tunisia: The first project was launched in cooperation with IMELS and aims to equip a textile manufacturer with 955 m² of FPC (Frein et al., 2014, pp. 1153ff.). The second project is called *Dissemination of Innovative Solar Thermal Applications for the Tunisian Industry* (DASTII) and is a cooperation between the ANME and the German International Cooperation (GIZ). This project is currently carrying out energy audits for the selection of a suitable company and provides information for this work.

SHIP is currently financially supported with a grant up to 30% of total costs, capped at about 65 EUR/m² (see Table 7, p. 23), with entirely financed feasibility studies, and with tax exemptions. Thus, it was tried to reapply the successful and approved policy instruments. But soft loans are not available yet and the main success factor of PROSOL Residential, the key role of the STEG as guarantor, has not been applied either. This might be a reason for limited engagement of financial institutions in addition to their low awareness for SHIP (Trabacchi et al., 2012, p. 26, 27).

4.6 Financial Institutions

As investments of SHIP systems may require external finance, a brief overview of financial institutions in Tunisia will be given. There are basically two financing options, either by foreign development banks, if credit lines are available, or by the private financial sector.

Credit lines of foreign development banks offer attractive conditions for investments in eligible projects. Currently, there is a credit line of the World Bank available providing 50 million USD to three selected private local banks. The latter were selected based on different criteria, such as familiarity with industrial and energy efficiency projects (WB, 2009, p. 2). Industries planning to invest in energy efficiency or

[9] 134 million USD, average 2005-2010 exchange rate EUR/USD=0,7482 (OANDA, 2014)

combined heat and power projects can apply for a loan with interest rates around 5%, repayment periods of twelve years, and grace periods up to three years (MIEM, 2011).

SHIP investments would not be eligible for this soft loan and industries would have to apply for a loan from foreign or local private banks. Acquiring loans from the private sector can be difficult, because investments in SHIP are not as profitable and there is little awareness and knowledge about the technology (Missaoui and Marrouki, 2012, p. 48). Examples of foreign development banks operating in Tunisia are the European Investment Bank (EIB), the African Development Bank (AfDB), or the Kreditanstalt für Wiederaufbau (KfW). The three local private banks selected by the World Bank project are the private Amen Bank (AB), the state-owned Banque de l'Habitat (BH), and the state-owned Bank of Financing Small and Medium Enterprises (BFPME). Given that they have undergone the World Bank's selection process, the granting of loans by one of these banks for financing a SHIP plant is more likely. The following banks were participating in the PROSOL program and are also of interest: Attijari Bank, Union Bancaire pour le Commerce et l'Industrie (UBCI), and the state-owned Société Tunisienne de Banque (STB).

5 Economic Assessment of SHIP in Tunisia

This section will investigate the economic feasibility of SHIP investments in Tunisian industries under current framework conditions. Firstly, methods used for economic assessment are presented. Secondly, the incurring cash flows of SHIP investments and corresponding assumptions are explained. Thirdly, the economics of SHIP investments for a reference case are assessed without financial policy instruments. To identify the largest financial barriers to investments in SHIP, a sensitivity analysis is carried out and a best case scenario is assumed to find out whether it is economically feasible under optimistic assumptions. In a last step, the impact of selected policy instruments on the economics of SHIP investments and on the state budget are analyzed. Based on the results recommendations for future energy policy are given.

5.1 Methods for Economic Assessment

There are several methods to assess economic feasibility of an investment. Reviewed studies assess economics of SHIP based on different investment appraisal methods (Reiners, 2011; Haagen, 2012; Calderoni et al., 2012) or solar heat generation costs (Lauterbach et al., 2011a; Haagen, 2012). Following the comprehensive structure of Haagen’s study, different methods for economic analysis are presented. Götze et al. (2008, p. 51) state, that “investment projects can be described as streams of (expected) cash inflows and outflows over the whole course of their economic life”. Those cash flows can be assessed with two basic methods of investment appraisal: the static and the dynamic method. Static investment appraisals are limited in their usefulness, because cash flows from different periods cannot be compared if time value of money[10] is not considered. Therefore, the dynamic method is most used in theory and company practice as it discounts cash flows from different points in time to the present. (Götze et al., 2008, pp. 46ff.)

5.1.1 Net Present Value

Net cash flows (NCF) are the sum of cash inflows (CIF) and outflows (COF). The present value (PV) of a NCF in t years with a discount rate d is calculated as follows (Götze et al., 2008, p. 52).

$$PV = \frac{NCF_t}{(1+d)^t} \qquad \text{with } NCF_t = CIF_t - COF_t \qquad (2)$$

Net cash flows that occur in time period t during the lifetime (LT) of an investment are discounted to the present t=0. The sum of the net cash flows discounted by using the discount rate d represents the net present value (NPV) (Götze et al., 2008, p. 54).

$$NPV = \sum_{t=0}^{LT} \frac{NCF_t}{(1+d)^t} \qquad (3)$$

Investors should only decide to invest in projects with a NPV greater than zero. Out of several investment projects, the one with the highest NPV should be chosen (Götze et al., 2008, p. 54).

[10] Cash available today will gradually increase its value, because of interest rates. Conversely, the value of cash in the future is lower than the same amount available today. Konstantin (2013)

Disadvantage of the NPV method are the two major assumptions: the existence of a perfect, unrestricted capital market, which implicates the unlimited possibility to borrow and lend money at the same uniform interest rate. And it is further assumed that cash flow surpluses can be reinvested at any time at the discount rate i (Bieg and Kussmaul, 2011, p. 102). An advantage is the absolute value of an investment in today's money, which allows direct conclusions in favor or against an investment decision (Crundwell, 2008, p. 171). Another advantage is its simple calculation.

Since the discount rate influences the NPV significantly, it should be chosen carefully. It is mostly seen as the financing cost of a project and therefore derived from the financial cost of capital invested in the project. If the project is entirely debt-financed, the cost of capital would be the interest rate i on the borrowed loan. For this study an equity-debt ratio of 30:70 is assumed, as it is common, that banks require a certain share of own contribution. The cost of a mix of equity and debt capital is usually determined using the weighted average cost of capital (WACC). It is calculated based on the share of debt and equity and their corresponding financing costs. For the share of equity, the rate of return on equity represents the financial cost of equity. Estimating a general rate of return on equity is difficult as it varies widely among different industries (Fama and French, 1997, p. 172). Therefore, no differentiation between costs of debt and equity is made in this study and a uniform discount rate is applied for the mentioned equity-debt ratio. Applying the idea of opportunity costs, the discount rate can also be considered as the rate of return of another investment which cannot be done based on the capital tie-up in the selected project. This also includes investments in capital markets at similar risk and duration (Götze et al., 2008, pp. 80f.).

There is no consensus among reviewed literature concerning the rate of the discount factor (see Table 8). Calderoni et al. (2012, p. 4) assumed a nominal discount factor of 4%, which appears to be low, taking into account that the inflation rate in Tunisia is even higher. For this study a real discount d_{real} rate of 7% seems reasonable. Since future cash flows will be influenced by inflation, the nominal discount rate is used. Using the following equation the respective nominal discount rate d_{nom} would be 11.7%, considering an average annual inflation rate e of 4.4% for the next 20 years in Tunisia.

$$d_{nom} = [(1 + d_{real}) * (1 + e)] - 1 \tag{4}$$

d_{real} in %	d_{nom}%	Investment	Source
10		Industries investing in RE	Short et al. (1995, pp. 7ff.)
5		Costs of solar heat generation	VDI (2014, p. 53)
	10	Costs of renewable power generation	IRENA (2013, p. 4)
8.25		Concentrated solar power (CSP) investment in Morocco	Kulichenko and Wirth (2012, p. 110)
7.5		CSP in MENA region	Kost et al. (2013, p. 11)
	3 and 6	Costs of SPH	Fichtner (2013, p. 35)
	4	Economics of SHIP in Tunisia	Calderoni et al. (2012, p. 4)
7	**11.7**		**This study**

Table 8: Discount Rates in Literature and Studies
Source: own illustration; see right column

Concerning the lifetime of a SHIP plant, the German Engineering Association (VDI, 2014, p. 64) and Heß and Oliva (2010, p. 26) recommend 20 years.

5.1.2 Internal Rate of Return

The concept of the internal rate of return (IRR) method is similar to the NPV method. The IRR is defined as the discount rate r for which the NPV is equal to zero, see equation (5)

$$0 = \mathrm{NPV} = \sum_{t=0}^{LT} \frac{\mathrm{NCF_t}}{(1+r)^t} \tag{5}$$

It is therefore the interest rate gained on the capital that was invested into a project. Only projects yielding an IRR higher than the interest rate for risk-equivalent financial investments or the cost of capital should be realized. The project with the highest IRR is chosen among alternatives (Götze et al., 2008, p. 68).

Götze et al. (2008, p. 74) see the major disadvantage of the IRR method in the unrealistic reinvestment assumption. That is, positive net cash flows can be reinvested earning the IRR. If the IRR of a project is for instance 15%, cash flow surpluses are assumed to be reinvested at 15%. Crundwell (2008) in contrast argues "that the reinvestment assumption does not exist". The inconsistency among textbooks was shown by Walker et al., (2009) who found out that out of 15 textbooks on engineering economics only three use this assumption. For this work, it is therefore not seen as major disadvantage that would imply its limited usefulness.

Crundwell (2008, pp. 179ff.) lists other disadvantages, such as possible conflicting results with the NPV method as a result of different cash flow profiles. But by using further investment appraisal methods besides NPV and IRR, it should be possible to establish a clear ranking of different alternatives. The difficulties calculating the IRR can also be seen as a drawback. Built-in functions of Microsoft Excel however, facilitate the determination of the IRR.

Advantage of the IRR over the NPV method is the intuitive value of the IRR, as it represents the earned interest on invested capital (Götze et al., 2008, p. 75).

5.1.3 Payback Period

Crundwell (2008), Götze et al. (2008), and Short et al. (1995) suggest the dynamic calculation of the PP, because the time value of money is considered. Konstantin (2013, pp. 185f.), however, argues that cash flow surpluses from energy savings should not be discounted, if the investor does not explicitly request it. According to Konstantin, it can be assumed that in case industrial companies define a maximum PP, they refer to the static payback period (SPP). Whereas Duffie and Beckman (2013, ch. 11.3) recommend discounted cash flows for the NPV and IRR method, they support Konstantin stating, that "the common way to calculate […] payback time is without discounting the fuel savings".

The time until the invested capital is recovered is called SPP. It is the point in time, when the accumulated NCFs are equal to zero. The SPP can be approximated using the linear interpolation formula, as seen in equation (6). t* is the last period in which the sum of all NCFs is still negative (Götze et al., 2008, p. 76). To calculate the SPP a VBA macro written based on the following equation.

$$\mathrm{SPP} \approx t^* + \frac{\sum_{t=0}^{t^*} \mathrm{NCF_t}}{\sum_{t=0}^{t^*} \mathrm{NCF_t} - \sum_{t=0}^{t^*+1} \mathrm{NCF_t}} \tag{6}$$

The dynamic PP involves discounting NCF, resulting in significantly longer amortization times. (Crundwell, 2008, pp. 164ff.)

The SPP does not take into account cash flows occurring after the payback period. The disadvantage limits its informative value concerning profitability, especially for projects with long lifetimes, such as SHIP plants. For example, the SPP method would favor project A, lasting five years with a SPP of 3 years against project B with a lifetime of 20 and a SPP of five years. It is likely, however, that B is more profitable, because of additional cash flow surpluses within the last 15 years. Therefore it should be combined with other methods to determine the relative profitability of a project (Götze et al., 2008, pp. 44, 76).

Despite its limitations with regard to the time value of money and profitability assessment it is very popular among industries. Alkaraan and Northcott (2006) interviewed large manufacturing companies in the United Kingdom and found out that it is the method applied first or second when evaluating investment projects. The widespread use in company practice is probably due to following major advantages of the SPPs. Its calculation and interpretation is simple. Furthermore, it can be seen as a measure of liquidity rather than of profitability. The shorter the SPP, the earlier the company can use the regained returns for other investments. Liquidity is especially important when a company has limited access to external funds (Crundwell, 2008, p. 166).

Since managers tend to be skeptical about reliable performance of SHIP plants (Cottret, 2011, p. 54), the SPP is a good measure to indicate how long the assumptions of future cash flows must hold until invested capital is recovered (Short et al., 1995, p. 64). Since the two latest textbooks concerning economics of RE investments propose the SPP, it is used for this work.

According to the literature, industries usually do not accept PP of investment in renewable technologies above five years (Konstantin, 2013, p. 185; Stryi-Hipp et al., 2007, p. 70; ESV, 2011, p. 58).

5.2 Cash Outflows

Investments in SHIP are characterized by cash outflows, such as equity-financed initial investment costs, annuities of loan repayments, operation and maintenance (O&M) costs, and consumption costs. Future cash inflows result from conventional fuel savings. There are no savings on the investment costs of the conventional heat system, because SHIP plants are mostly retrofitted with existing systems. Moreover, in case of solar system failure or low irradiation, conventional heating serve as a back-up and must be designed to provide the peak load (VDI, 2014, p. 60).

Listed equations are an example for the reference case using stationary collectors.

For the economic analysis a collector aperture area of 1000 m^2 is assumed which is equal to the dimension of the first Tunisian pilot plant for SHIP. Both stationary and concentrating technologies will be analyzed for feasibility.

5.2.1 Total Investment Costs

Total investments cost of SHIP plants are made up of costs of equipment (e.g. collectors, support construction, storage tanks, pumps, controllers, piping or heat exchangers) and of installation (Duffie and Beckman, 2013, ch. 11.1). Immaterial costs of planning and commissioning should also be taken into account (VDI, 2014, p. 61). Sometimes costs are divided into costs for solar loop and costs for integration (Mauthner et al. 2013, p. 9), it is important to consider both for the system costs of the entire plant. To estimate investment costs for a 1000 m² SHIP plant in Tunisia, system costs used by other studies and costs of realized projects are taken into account.

For **stationary** technologies, specific investment costs of solar systems using FPC or ETC are relevant. The respective system costs estimated by Fichtner and Lauterbach et al. differ probably because they are based on different aperture areas (see Table 11, p. 34).

There is little information available on costs of realized SHIP plants and the number of large SHIP plants with an aperture around 1000 m² is still small. According to Salvatore Moretta, the specific total investment costs of the Benetton plant in Tunisia amount to about 345 EUR/m² (see expert interview in appendix P, p. 79). This amount appears to be low compared to the system costs of four other large SHIP plants (FPC), built in Europe after 2010 (see Table 9). Although prices of ETC tend to be higher than those of FPC, the price difference is not apparent when comparing the system costs of SHIP plants using FPC and ETC. The given sample of realized projects is too small to derive a general reference, but it shows the high cost fluctuations that are typical for technologies during an early stage. It serves also to estimate the range of investment costs which is relevant for the sensitivity analysis.

Plant (Country)	**Process** (Temp. in °C)	**Col-lector**	**Specific system costs** in EUR/m²	**Aperture area**[11] in m²	**Year**	**PP** (incl. subsidy)	**Source**
Benetton Textiles (TUN)	Dyeing (60)	FPC	345	869	2014	n.a.	Frein et al. (2014, p. 1162)
Göss Brewery (AUT)	Brewing (80)	FPC	815	1375	2013	10 (50%)	Mauthner et al. (2013)
LEITL Con-crete (AUT)	Drying (45)	FPC	1,045	287	2010	n.a.	SO-PRO (2010b)
Montesano Meat (ESP)	Washing (40-45)	FPC	763	229	2011	7 (33%)	SO-PRO (2014)
Merl Food (DEU)	Washing (60)	FPC	575	517	2010	9 (30%)	SO-PRO (2010a)
Steinbach Metal (DEU)	Preheating (60-80)	ETC	600	400	2008	7 (50%)	ESV (2011)
Hustert Gal-vanik (DEU)	Heating Baths (80)	ETC	724	221	2011	(30%)	SO-PRO (2014) ESV (2011)

Table 9: Key Data on SHIP Plants Using FPC
Source: see right column in table

[11] If gross collector area of FPC is given only, it is multiplied by 0.91 to estimate aperture area. This ratio was calculated from those plants providing both gross collector and aperture areas.

To assess the impact of the choice of stationary collector technology on specific investment costs, a closer look will be taken at the distribution of costs. The SPH guideline of Heß and Oliva (2010, p. 26) refers to distribution of cost of large solar thermal installations, that were reported by Peuser (2002, p. 10) and evaluated in more detail in Peuser et al. (2009, pp. 248ff.). The cost distribution represents costs of realized systems designed to provide solar heat for domestic purposes, but not for industrial processes. Therefore, costs of process integration are not considered. Mauthner et al. (2013, p. 9) split up the total investment costs of the SHIP plant installed at Göss Brewery (see Figure 14). It shows that almost all costs of the FPC-SHIP plant were spent on equipment and the integration of solar heat, with only a small part accounting for immaterial costs. In this case, integration costs were especially high, because they include costs of the integration of district heat and of the reconstruction of mash containers. Costs of FPC only account for about a fifth of total costs. The low share of collector costs might explain why the specific total investment cost of the two listed SHIP plants using ETC are not higher than the FPC-plants.

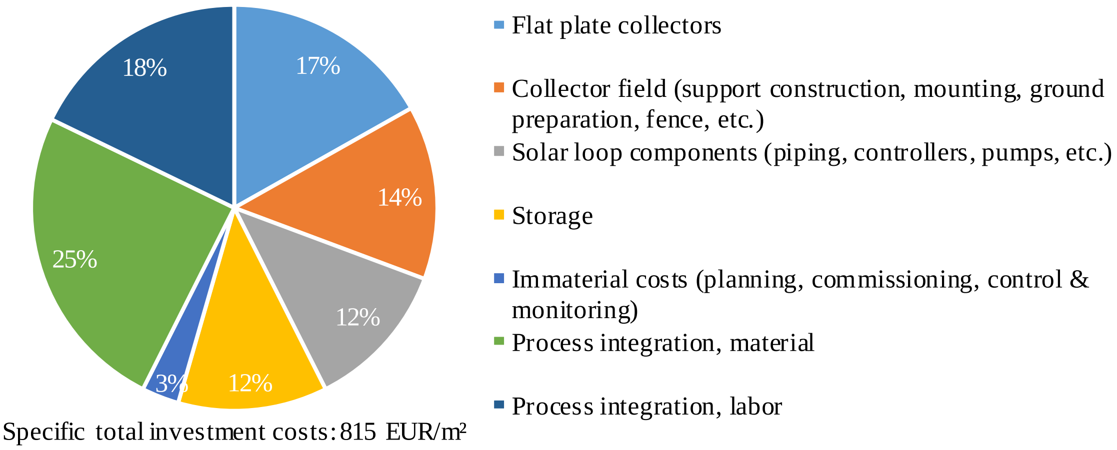

Figure 14: Distribution of Total Investment Costs of SHIP Plant at Göss Brewery (1375 m²)
Source: own illustriation; Mauthner et al. (2013, p. 9)

Duffie and Beckman (2013, ch. 11.1) separate investment costs into costs that are related to the size of the collector field and area-independent costs, such as planning or controllers. Cost degression with increasing collector area are expected, because the mentioned area-independent costs are distributed across the entire area and specific costs for storage and heat exchangers decrease as well. Furthermore, quantity discounts for collectors are granted by suppliers (Lauterbach et al., 2011a, p. 7). However, Peuser et al. (2009, p. 250) state that the economy of scale effect for large solar thermal systems is still small. This is probably due to the early stage of maturity of large SHIP plants that comes along with limited experience and high uncertainties of system integration costs (Pietruschka et al., 2012, p. 2).

All in all, it is difficult to generalize system costs for a 1000 m² SHIP plant, as costs vary significantly depending on the system concept, e.g. use of storage or heat exchanger and point of integration. The assumed system costs are a reference and varied later within the sensitivity analysis.

For this work specific investment costs of 1000 m² SHIP plants using FPC are assumed to be 400 EUR/m² as reference. It is above system costs of the Benetton plant, which seem to be very low compared to other plants realized in Europe. And below the system costs estimated by Lauterbach et al.[12] for a smaller plant size. Material costs of European SHIP plants are assumed to hold for Tunisia as well, due to geographical market proximity. The influence of lower labor cost are neglected, as skilled labor is needed for installation and possible wage differences are assumed not to impact system costs significantly. Reference system costs of ETC SHIP plants are estimated at a higher level than FPC based on the assumptions of the two literature references.

SHIP plants using **concentrating** technologies are less widespread. Only a tenth of registered plants operate with concentrating collectors (see Figure 1, p. 3). The majority of reported plants have been built during the last five years, therefore there is probably even less experience with concentrating technologies in SHIP applications.

Reiners based his feasibility study of SHIP plants on relatively low specific system costs and assumed considerable cost degression for larger plants. The reference costs are taken from six planned and realized systems. But it is not clear where they were constructed (as prices may differ regionally), which of the six plants have been already realized (as cost of planned plants often differ from realized ones), and if costs account for the entire system or the solar loop only (as stated costs are taken from a PTC supplier). Haagen states that the assumed "price of 400 EUR per m² is rather low" for a large 8000 m² SHIP plant. It is not mentioned on what his assumptions are based.

According to Kalogirou (2003, p. 355) cost reductions for concentrated larger SHIP plants are significant. Stefan Minder, CEO of NEP Solar, confirmed this (see mail conversation in appendix Q, p. 80).

Specific total investment costs of large SHIP plants using PTC and built in Europe and North Africa since 2003 range from about 1000 to 1200 EUR/m² (see Table 10). There was no information available on SHIP systems operating with LFR. Minder (2014, p. 27) points out that half the costs of concentrated SHIP plants incur for the installation and commissioning of the collector field, including collector costs, instrumentation, and controllers. The high share of costs of concentrating colletors is the main reason for higher system costs compared to stationary SHIP plants.

Plant (Country)	**Process** (Temp. in °C)	**Specific system costs** in EUR/m²	**Aperture area** in m²	**Year**	**PP** (incl. subsidy)
El Nasr Pharma (EGY)	Steam (175)	1025[13]	1900	2003	n.a.
Emmy Dairy (CHE)	Steam (140-180)	957	627	2012	10 (50%)
Cremo Dairy (CHE) PTC Type: PolyTrouch 1800	Superheated water (125-170)	1205	581	2013	10 (50%)

Table 10: Key Data on SHIP Plants Using PTC in Switzerland and Egypt
Source: Cottret (2011), AEE INTEC (2014), Minder (2014)

[12] It is likely that those costs were underestimated. They were assumed based on collector costs as a starting point and added additional system costs based on the cost distribution of large solar thermal systems published by Peuser et al. (2009). SHIP plants have additional costs of process integration, which seem not to be included.

[13] Estimation: pilot plant was result of study with 2.2 million USD budget, about 1.95 million EUR (average exchange rate 2013: 1 USD=0.8854 EUR)

The reference system costs of a concentrated SHIP plant with a 1000 m² aperture area are assumed to be 700 EUR/m². The system costs of the Egyptian SHIP plant cannot be used as a reliable benchmark, as system costs might be overestimated. Considering economies of scale the specific investment costs used for this study are below the smaller realized PTC-SHIP plants.

FPC in EUR/m²	ETC in EUR/m²	Concentrating in EUR/m²	Aperture Area in m²	Source
375	500	-	1000	Fichtner(2013, pp. 34f.)
450	600	-	500	Lauterbach et al. (2011a, p. 7)
-	-	400 (LFR)	8000	Haagen (2012, pp. 61ff.)
-	-	350 (PTC)	1000	Reiners (2011, pp. 80f.)
400	**500**	**700**	1000	**This study**

Table 11: Reference System Costs of other Studies and this Study
Source: see right column in table

5.2.2 Loan Repayments

If the total investment costs of a SHIP plant C_{inv} are partly financed by a loan, identical annual loan repayments, also called annuities, incur. The annuity a is the product of the annuity factor f_a and the loan whose amount depends on the grant rate GR and the equity ratio ER (see (8)). The annuity factor depends on the duration n and the interest rate i of a loan (Götze et al., 2008, p. 53).

Abdel-Dayem (2011, p. 6) assessed the economics of an Egyptian SHIP plant and assumed an interest rate of 12%. Kulichenko and Wirth (2012, p. 110) analyzed cost-effectiveness of CSP plants for electricity generation in Morocco and assumed 9% as commercial interest rate. The loan conditions depend strongly on the previously relationship of the industrial company and banks. In the case of long-term cooperation between a bank and a stable company, interest rates at TMM[14] + 3% and repayment period of five years can be granted (see expert interview with Ali Ben Hmid in appendix P, p. 79). These conditions are assumed for the reference case.

$$f_a = \frac{(1+i)^n * i}{(1+i)^n - i} \quad (7)$$

$$a = C_{inv} * (1 - GR) * (1 - ER) * f_a \quad (8)$$

5.2.3 O&M Costs

The German Engineering Association VDI (2014, p. 61) recommends annual costs for O&M of large solar thermal systems at 1% of total investment costs. For concentrating technologies, O&M costs are assumed to be higher due to the maintenance of tracking systems and cleaning of the reflectors. Although O&M costs are already higher due to higher investment costs, Kalogirou (2003, p. 355) estimates O&M costs at 2% of investment costs. Today, there is already more experience with concentrating technologies and they have matured compared to eleven years ago, when Kalogirou made his assumption.

[14] The Money Market Average is a reference rate set by the Tunisian Central Bank on a monthly basis. It is currently 4.98% BCT (2014)

Furthermore, cleaning can be done by unskilled labor at low costs in Tunisia. Therefore O&M costs of 1.5% are assumed for concentrating technologies.

As SHIP plants become older, they might require more maintenance. An annual increase of 0.5% for stationary and 1% for concentrating technologies was assumed by Kalogirou (2003, p. 355). As stated before, it is expected that concentrating technologies are more mature by now and a uniform increase of 0.5% is assumed for both technologies. Additionally, it is assumed that O&M costs will be paid at the end of each period and rise with inflation rates e.

$$C_{O\&M,t} = C_{inv} * 0.01 * (1 + \text{annual O\&M increase})^{t-1} * (1 + e)^{t} \quad (9)$$

5.2.4 Electrical Consumption Costs

The solar system consumes electricity for pumps, valves, and tracking system. Electrical consumption of large systems is assumed at 2% of the useful solar yield (VDI, 2014, p. 62). For concentrating technologies 2.5% is expected due to the additional operation of the tracking system. Basing consumption costs on the initial useful solar yield $Q_{usol,0}$ neglects the fact that a solar system might be operating during periods in which no heat is demanded. If a storage tank is installed, the generated heat is stored and used later. This implies thermal losses and underestimated consumption costs due to lower useful solar yield than actual yield. These periods are usually short. For longer periods without heat demands, e.g. on weekends, systems are not operating and consumption costs would be overestimated by basing them on the overall possible solar yield. Therefore it appears reasonable to base them on useful solar yield, despite slight underestimation. Electricity bills are assumed to be paid at the end of the period. Higher energy prices p_{en} increases are assumed within the first six years (see Table 5, p. 18).

$$C_{con,t} = Q_{usol,0} * 0.02 * p_{el} * (1 + p_{en} \text{ increase } 1)^{t} \qquad \text{for } t = \{1, 2, \ldots, 6\} \quad (10)$$

$$C_{con,t} = Q_{usol,0} * 0.02 * p_{el} * (1 + p_{en} \text{ increase } 1)^{6} * (1 + p_{en} \text{ increase } 2)^{t} \qquad \text{for } t = \{7, 8, \ldots, LT\} \quad (11)$$

All in all, the following cash outflows are expected within the lifetime of a SHIP plant.

The first cash outflow is the share of total investments costs financed with equity, according to the equity ratio ER, and reduced by the respective grant rate GR:

$$COF_0 = C_{inv} * (1 - GR) * ER \qquad \text{with } C_{inv} = c_{inv} * A_a \quad (12)$$

The total cash outflow during the loan repayment period n is:

$$COF_t = a + C_{O\&M,t} + C_{con,t} \qquad \text{for } t = \{1, 2, \ldots, n\} \quad (13)$$

and after the loan has been paid back, costs for O&M and electrical consumption incur:

$$COF_t = C_{O\&M,t} + C_{con,t} \qquad \text{for } t \in \mathbb{N} \text{ and } n < t \leq LT \quad (14)$$

5.3 Cash Inflows

Cash inflows incur in form of fuel savings. They are derived from the annual useful solar system yield, which is the amount of SPH used by industrial processes. Depending on the demand profile of a company the useful solar yield differs from the actual available solar yield. If the industrial company does not operate on weekends for instance, the solar energy yield that could be generated is not used. It can be stored, but this comes along with additional thermal losses. Figure 15 illustrates how the first cash inflow is calculated. The cash flows in the following periods also will be influenced by inflation rates, fuel price increases, and system degradation. In the following section the necessary input data will be collected.

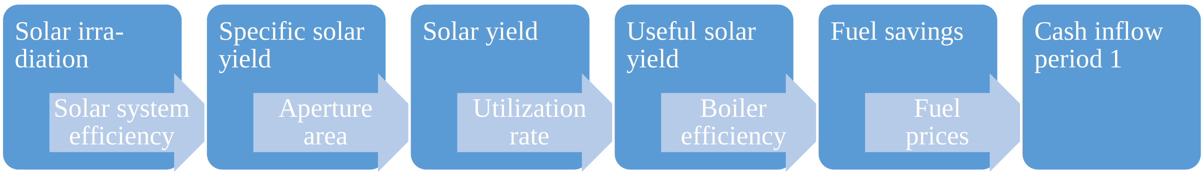

Figure 15: Calculation of the First Cash Inflow
Source: own illustration

5.3.1 Solar Irradiation

As seen in Table 12, solar irradiation varies slightly within the northern (Tunis) and central (Gabes) regions of Tunisia. Stationary collectors can collect direct and diffuse irradiation and are usually installed at an optimal inclined angle to enhance performance. The satellite-based PVGIS database provides relevant data on global irradiation at an optimal tilted angle. It is about 1.14 times higher[15] than global irradiation on a horizontal plane. The meteorological data available for the simulation program Greenius is time-resolved and of high quality and shows a factor of 1.13. Multiplying the total average for GHI with a factor of 1.13 equals 2093 kWh/m²/a. For calculating the annual solar yield of concentrating technologies the average DNI level of 2009 kWh/m²/a is used.

GHI in kWh/m²/a			**DNI** in kWh/m²/a			**Source**
North	Center	**Average**	North	Center	**Average**	
1743	1891	1817	1853	2040	1947	Solar Med Atlas
1719	1820	1770	1814	1888	1851	SoDa, 2005
1856 (2112)	2047 (2332)	1952 (2222)	2113	2311	2212	PVGIS (optimal inclination angle: 31°)
-	-	-	1800	2250	2025	Trieb et al.
1716	-	-	-	-	-	El Ouderni et al.
1759 (1988)	1919 (2168)	**1839 (2078)**	1895	2122	**2009**	**Total Average** (Irradiation at optimal angle)

Table 12: Annual Solar Irradiation in Northern and Central Tunisia
Source: Solar Med Atlas (2010), SoDa (2005), (PVGIS, 2012)), (Trieb et al., 2005), El Ouderni et al. (2013)

15 $\frac{2222}{1952}$

5.3.2 Specific Solar Yield

The specific solar yield depend s on the overall efficiency of the solar system, which indicates how much solar energy is transformed into solar heat and available for industrial processes. The system efficiency is composed of the collector efficiency and the thermal losses caused for example by piping, heat exchangers, and storage tank (Peuser et al., 2009, pp. 218ff.). The resulting specific annual solar yield is then multiplied by the aperture area to determine the annual solar yield. The latter is usually determined using simulation programs, such as TRNSYS (Kalogirou, 2003); (Lauterbach et al., 2011a; Heß and Oliva, 2010) or Greenius (Reiners, 2011). The latter is a more user-friendly freeware from the German Aerospace Center (DLR). Simulations consider thermal loads of industrial processes, climatic conditions, and collector parameters to estimate the technically and economically optimal annual solar yield of a SHIP installations. This work focuses on the economics of SHIP plants for different temperature ranges and processes. Simulating the variety of different SHIP installations is not possible and necessary for this work. Therefore system efficiencies are taken from the literature to determine the expected annual solar yield.

As illustrated in Figure 2, p. 4 collector efficiencies decrease as operating temperature increases. In Table 1, p. 5 temperature ranges for respective collector technologies were assumed to facilitate the economic assessment. For FPC process temperatures ranging from 40 °C to 80 °C are assumed and as a reference an average operating temperature of collectors is chosen at 65 °C[16]. Processes at lower temperatures would yield higher collector efficiencies.

Thermal losses between the collector field and the feed into the process also differ for different concepts. If solar heat is generated close to the load (short piping distance, less pipe losses) and fed in directly without heat exchanger or storage tanks, system efficiencies increase accordingly. This would be the best case, which is rare. For the reference case it is assumed that heat exchangers are installed and a storage tank is used, since most processes do not operate continuously.

Frein et al. (2014, p. 1158) simulated the FPC-Benetton plant with heat exchangers and storage tanks. Results predict that on average of 43% solar energy can be transformed and delivered in form of SPH after taking into account respective heat losses. The operating temperatures are about 80 °C. For the reference case at operating temperatures of 60 °C collector efficiencies would be about 10 percentage points higher (see Figure 2, p. 4). Peuser et al. (2009, p. 216) compared theoretical efficiencies based on simulations and actual efficiencies based on measurements of solar loops and found out that actual efficiencies are 7 percentage points lower. As a reference for system efficiencies using FPC 45% is assumed.

Fichtner (2013, pp. 30ff.) used the data of a survey carried out by the German Solar Industry Association (BSW) to determine the average specific solar yield of ETC SHIP systems in Germany. The overall system yield including thermal losses of system integration is on average 42% at operation temperatures

[16] The average process temperature within that range would be 60 °C, requiring operating temperatures of about 65 °C due to thermal losses between collector field and feed-in.

of 80 °C (for details on calculation see Table 30, p. 61 in appendix). For operation temperatures at 100 °C for the reference case, a system efficiency of about 38% is assumed.

Haagen (2012, p. 61) assumed that specific annual solar yields represent 40% of the DNI. His assumptions is based on simulations of SHIP plants using LFR. Since simulated and real efficiencies vary, a system efficiency of 33% is assumed for concentrating technologies.

In addition to decreasing collector efficiencies with rising operating temperatures, heat losses increase between the solar loop and the feed-in. Therefore, system efficiencies drop for SHIP applications providing SPH at higher temperatures.

The initial system efficiency decreases as the solar system ages. Kalogirou (2009, p. 44) assumes 1% of system degradation per annum for domestic solar water heaters, but does not consider O&M costs. This economic assessment considers increasing O&M costs and it is therefore assumed that the performance of maintained SHIP installation will decrease by 0.5%.

The specific annual solar yield q_{SOL} for is calculated by multiplying relevant solar irradiation G_{tilt} or DNI with the respective system efficiency η_{sys} in %:

$$q_{sol} = G * \eta_{sys} \qquad [q_{sol}] = \frac{kWh}{m^2 * a} \qquad (15)$$

The annual solar yield Q_{sol} is calculated by multiplying the specific annual solar yield q_{sol} with the aperture area A_a in m²

$$Q_{sol} = q_{sol} * A_a \qquad [Q_{sol}] = \frac{kWh}{a} \qquad (16)$$

5.3.3 Useful Solar Yield

The annual solar yield is the amount of heat that is available for processes. But when no heat is needed it cannot be used. Only a few processes operate seven days a week and have a constantly high heat demand. The respective utilization rate would be 100%, since all the generated solar heat can be fed in at all times. For the reference case it is assumed that the process operates seven days a week, in two shifts during the day, with few annual production stops, but with fluctuating demands. Karagiorgas et al. (2001, p. 161) assume around 80% for FPC providing SPH at process level. This value is used as a reference for stationary collectors. One of the advantages of concentrating collectors is the capacity to generate steam that can be fed in at supply level. It is then transported to respective processes and therefore not affected as much by fluctuating heat demands. An utilization rate of 95% is assumed for concentrating technologies (Battisti et al., 2007, pp. 54f.).

The useful annual solar yield Q_{usol} is the product of Q_{sol} and the utilization rate UR in %

$$Q_{usol} = Q_{sol} * UR \qquad [Q_{usol}] = \frac{kWh}{a} \qquad (17)$$

5.3.4 Fuel Savings

If no solar system provides SPH, a conventional boiler would generate the useful annual solar yield by burning fuel. To determine how much fuel is saved by using SPH, the useful solar yield Q_{usol} is divided by the boiler's efficiency η_{boil}, which is assumed to be 85% (VDI, 2014, p. 65). Company visits within the GIZ project confirmed this average boiler efficiency for Tunisia.

$$S_{fuel} = \frac{Q_{usol}}{\eta_{boil}} \qquad [S_{fuel}] = \frac{kWh}{a} \tag{18}$$

The product of annual fuel savings S_{fuel} and respective fuel price p_{fuel} (in EUR/kWh) is the annual fuel cost saving and the cash inflow (in EUR/a) of the SHIP investment. It is assumed that energy bills are paid at the end of period, considering energy price increases.

$$CIF_t = S_{fuel} * p_{fuel} * (1 + p_{en} \text{ increase } 1)^t \qquad \text{for } t = \{1, 2, \ldots, 6\} \tag{19}$$

$$CIF_t = S_{fuel} * p_{fuel} * (1 + p_{en} \text{ increase } 1)^6 * (1 + p_{en} \text{ increase } 2)^t \qquad \text{for } t = \{7, 8, \ldots, LT\} \tag{20}$$

The total cash inflow during the first six years is:

$$CIF_t = \frac{G * \eta_{sys} * A_a * UR * p_{fuel} * (1 + p_{en} \text{ increase } 1)^t}{\eta_{boil}} \tag{21}$$

5.4 Economics without Financial Policy Instruments

In this section the economics of SHIP investments are assessed without taking into account existing grants. This allows to find out about the true costs of SHIP installations. A sensitivity analysis shows the impact of assumed input parameters and the best case scenarios assesses the economics under optimistic assumptions.

5.4.1 Reference Cases

The economics of three SHIP installations using FPC, ETC and concentrating technologies are assessed for both the replacement of NG and of FO. Within this study an economic assessment tool was developed and used for the calculations that were based on the inputs shown in Table 13 (for more details on the calculation and interim results, see Table 34 and Table 35, pp. 66f. in appendix).

Figure 23 to Figure 25, p. 68 in the appendix show the resulting cash flows for the three different technologies replacing NG as fuel. All three SHIP technologies are not economically feasible under current framework conditions in Tunisia without financial policy instruments, as they show a negative NPV and a SPP superior to the lifetime of 20 years (see Table 14). Concentrating technologies show poorer economic viability in comparison to the stationary technologies. The assumed higher utilization rate due to possible steam generation does not increase fuel savings sufficiently. Cash outflows of concentrating technologies are high due to elevated O&M costs and increase yearly by about 5% due to inflation and O&M cost increases. Fuel cost savings, however, only increase by around 4.5% per year as a combined result of both energy price increases and system degradation. This leads to low net cash flows with decreasing growth rates for concentrating technologies (see Table 35, p. 67 in appendix). Stationary collectors have the advantages to collect both direct and diffuse radiation to yield high efficiencies at low temperatures, and to have lower investment costs which result in better economic performance.

Input Parameter	Term	Unit	Uniform		
Aperture area	A_a	m²			1000
Lifetime	LT	a			20
Real discounting factor	d_{real}	%			7
Inflation per year	e	%/a			4.4
Nominal discounting factor	d_{nom}	%			11.7
Energy prices	p_{en}				
Electricity	p_{el}	EUR/kWh			0.0819
Natural gas	p_{NG}	EUR/kWh			0.0163
Fuel oil	p_{FO}	EUR/kWh			0.0228
Annual increase 2015-2021		%/a			10
Annual increase 2021-2035		%/a			5
			FPC	**ETC**	**Concentrating**
Cash Outflows					
Specific total investment costs	c_{inv}	EUR/m²	400	500	700
Grant rate	GR	% of C_{inv}	0	0	0
Equity ratio	ER	% of $C_{inv,red}$	30	30	30
Loan					
Interest rate	i	%	8	8	8
Grace period		a	0	0	0
Repayment period		a	5	5	5
O&M costs	$C_{O\&M}$	% of C_{inv}	1	1	1.5
Annual increase		%/a	0.5	0.5	0.5
Electrical consumption		% of Q_{usol}	2	2	2.5
Cash Inflow					
Irradiation	G_{tilt}, DNI	kWh/m²/a	2078	2078	2009
System efficiency	η_{sys}	% of G	45	38	33
Annual degradation		%/a	0.5	0.5	0.5
Utilization rate	UR	% of Q_{sol}	80	80	95
Boiler efficiency	η_{boil}	%	85	85	85

Table 13: Input Parameters for Reference Cases
Source: own illustration

Figure 26 to Figure 28, p. 69 in appendix illustrate the results in case of FO being replaced. The avoided fuel costs are higher, but the NPV remain negative for all three technologies. SHIP investment using FPC has a SPP below the lifetime because future cash inflows are not discounted. Its IRR is positive, but below the annual inflation rate (see Table 14). To find out to which extent different factors influence the economic performance SHIP investment, a sensitivity analysis is done in the following section.

Value	Unit	Replaced Fuel	FPC	ETC	Concentrating
NPV	EUR	NG	-243,057	-375,014	-626,831
		FO	-166,232	-310,140	-562,151
IRR	%	NG	-1.18	-6.17	-16.55
		FO	3.66	-1.55	-8.71
SPP	a	NG	21.62	30.44	>60
		FO	15.89	22.15	36.81

Table 14: SPP, NPV, and IRR of Reference Cases
Source: own illustration

5.4.2 Sensitivity Analysis

The economic assessment is based on several assumptions which come along with certain uncertainties. To assess the impact of assumed input parameters on the output of the investment appraisal and the effect of changes in framework conditions, a sensitivity analysis is carried out (Götze et al., 2008, pp. 280ff.). The SPP is chosen as target value, because it is the most intuitive method and an important criteria among industries in Tunisia. As a reference for the analysis both stationary and concentrating technologies will be considered. FPC and ETC are not differentiated, because relevant input parameters are within similar ranges. Furthermore, NG is expected to be replaced, because it is the most common fuel.

Table 15 lists the parameters that are varied in 5% steps within a selected range, while the other parameters remain constant. The other parameters not listed in the table correspond to the reference case of the previous chapter. The selection of input parameters and respective ranges are briefly commented in the following.

Input parameter		Unit	Minimum		Reference	Maximum	
			absolute	relative	absolute	absolute	relative
Annual inflation		%/a	2	45%	4.4	7	159%
Natural gas price		EUR/kWh	-	-	0.0163	0.037	227%
Annual energy price increase		%/a	1	14%	7	10	143%
Interest rate		%	5.5	69%	8	12	150%
Boiler efficiency		%	75	88%	85	95	112%
Specific Total Investment Costs	stat.	EUR/m²	300	67%	450	800	178%
	conc.		400	57%	700	1000	143%
O&M	stat.	% of C_{inv}	0.5	50%	1	2	200%
	conc.		0.75	50%	1.5	3	200%
System efficiency	stat.	% of G	30	75%	40	50	125%
	conc.		25	76%	33	40	121%
Utilization rate	stat.	% of Q_{sol}	50	63%	80	100	125%
	conc.		60	63%	95	100	105%

Table 15: Input Parameter and Range for Sensitivity Analysis of SPP for SHIP Investments
Source: own illustration

Annual inflation rates are currently more than 6%, therefore the maximum is set at 7%.

NG prices do not represent a future trend, but a present fact. Yet, they are varied up the level of the mean cost price of NG (incl. VAT). This price can be seen as the minimum retail price if energy subsidies were abandoned.

Annual energy price increase are assumed to increase at a uniform rate of 7% as a reference value. The previous assumption of higher price increasing during first six years is not taken into account to simplify the analysis. The minimum is set on the basis of global energy prices and the maximum considering the rate of increase of past energy price increases in Tunisia. A 10% annual energy price increase implies that prices will almost have doubled after 7 years and increased sixfold in twenty years. It also implies that the retail price would be above the mean cost price in 10 years if the latter is assumed to increase with global energy prices at 1% (see Table 33, p. 65 in appendix). This would imply that subsidies would have been abandoned for NG for the following years and energy taxes resulted in gradually increasing energy prices. This shows the optimistic assumption of a 10% annual energy price increase.

Interest rate is set at a minimum according to favorable loan conditions available for selected RE projects by foreign credit lines. The maximum assumes the case of high skepticism in the financial sector towards new technologies.

Boiler efficiencies vary depending on the utilization rate, the type, and the age of the boiler (VDI, 2014, pp. 65f.).

Specific total investment costs vary significantly among reviewed literature and experiences from realized SHIP plants. For stationary collectors the minimum is slightly below investment costs of the Benetton plant and the maximum value can occur when integration is difficult, as was the case at the Göss brewery. Concentrating technologies are varied according to low systems costs of reviewed literature and high system costs of realized plants.

O&M costs are varied half and double the reference value, both for stationary and concentrating technologies.

System efficiencies vary strongly depending on operating temperatures. Simulations with Greenius for a 1000 m² SHIP plant in Sicily using the selective FPC (for technical data see Sonnenkraft (2014)), without storage, but piping losses at operating temperatures of 40 °C resulted in 58% system efficiencies. Due to differences of simulation and measurement results, a maximum of 50% is assumed to be possible for favorable conditions. The minimum is set in view to low system efficiencies at high operating temperatures. Concentrating technologies are varied in similar relative ranges.

Utilization rate can reach up to 100% if thermal loads are always higher than solar yields, which implies that no storage tank is needed and SPH can be fed in at any time. In contrast, if processes have fluctuating heat demands and low working hours per week and throughout the year, SPH cannot be used, resulting in low utilization rates. As stated before, concentrating technologies are not affected as much by fluctuating demands.

Irradiation only varies around 5% at suitable locations for SHIP in Northern and Central (see Table 12) Tunisia and is therefore not assessed. Since the SPP method does not discount future cash flows, neither the discounting factor nor the impact of longer repayment period are assessed. The latter is usually advantageous as future costs in the form of annuities are of lower present value. The static appraisal however does not consider the time value of money, and a longer repayment period would lead to additional interest costs. Consumption costs are not varied either, because they account only for a small share of cash outflows (see Table 35, p. 67 in appendix) and do not vary significantly according to literature.

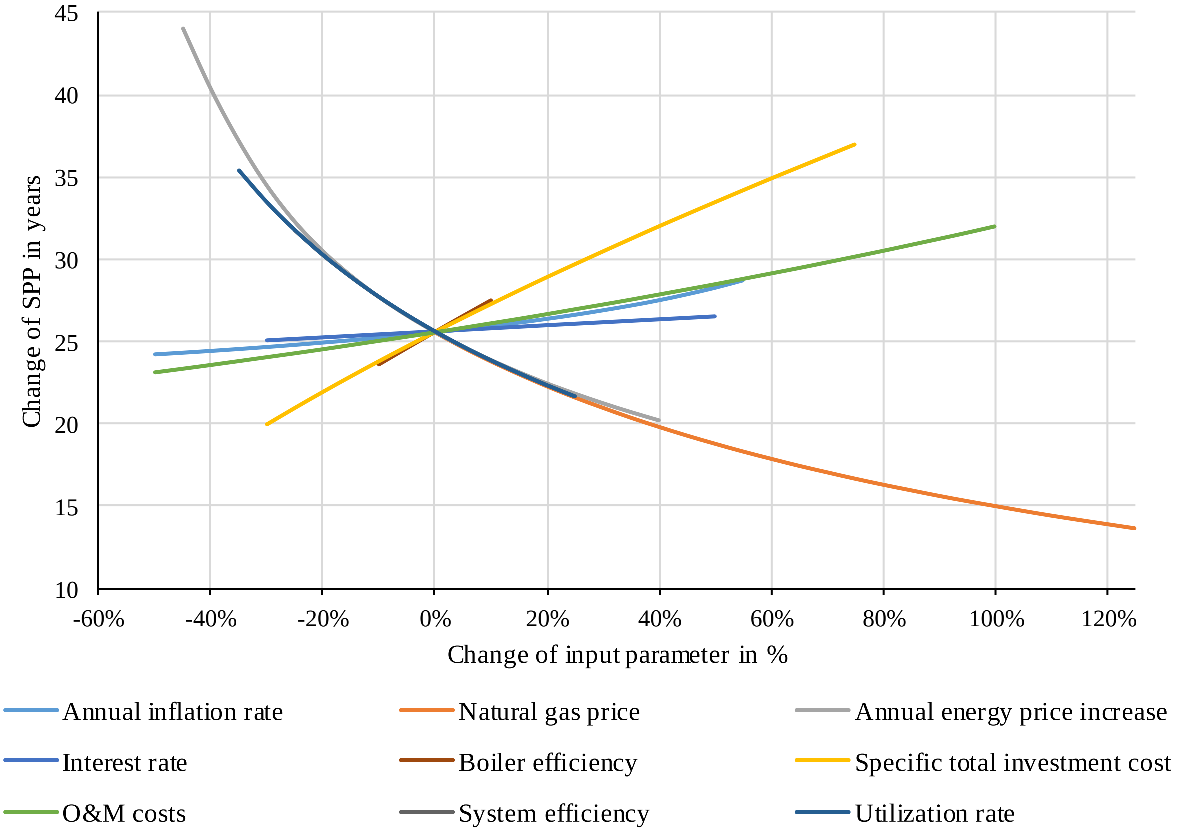

Figure 16: Sensitivity Analysis of SPP of SHIP Investment using Stationary Collectors; Replaced Fuel: NG

Source: own illustration

Figure 16 shows the result of the sensitivity analysis of the reference case using stationary technologies. The SPP is 25.6 years for unvaried reference parameters.

Parameters were varied according to their interval or until the SPP amounted up to 45 years (about 75% more than the reference SPP).

Increased annual inflation rates result in elevated future O&M costs and show therefore a similar impact as rising O&M costs, but non-linear growth. If NG retail prices were not subsidized and as a result more than twice as high, the SPP would decrease by around 47% to less than 14 years due to high fuel cost savings (see Table 36 and Table 37, pp. 70f. in appendix). The higher annual energy price increase the higher fuel cost savings. But since energy price increases also lead to marginally higher electrical consumption costs the curve shows a slightly different course than price increases for NG only. Varied interest rates affect the amount of loan repayments only to a small extent, which shows the limitations of soft loans as a financial policy instrument. An interest rate at 5.5% instead of 8% lowers the SPP only by about half year. Boiler efficiencies vary within a small interval have therefore only limited absolute impact. NG price, system efficiency, and utilization rate show the same curve, as they are all part of the numerator of the cash inflow equation (21). But depending on their interval they have different maximum impacts. As stated before, current NG prices are not an assumption, but it shows their importance to the economics of a SHIP investment. Utilization rate and system efficiencies are varied within a similar range, therefore the curve of varied utilization rate covers the one of system efficiency. Specific total investment costs impact various factors, such as equity investment, loan repayments, and

O&M costs. They have the strongest relative impact and if they were at 300 EUR/m² (30% less than the reference case) the PP would be about 20 years. O&M costs show a linear growth and can have a strong absolute impact due to the large interval.

Figure 29, p. 72 in appendix illustrates the results of the sensitivity analysis for concentrated SHIP investments. The SPP is around 42 years for the adapted[17] reference case. The resulting curves of varied input parameters show significantly steeper increases compared to the stationary case. That is, varied input parameters have a larger impact on the resulting SPP than for the stationary case. This is due to the difference in cash flow structures. Stationary technologies have smaller cash outflows due to lower investment costs and higher cash inflows due to elevated solar yields. Hence, the resulting net cash flows for stationary collectors are higher than net cash flows of a concentrating SHIP investment. Therefore cumulated net cash flows which are the basis for the calculation of the SPP grow faster for stationary collectors yielding lower SPP. The absolute impact of the same relatively varied input parameter is smaller for lower net cash flows. As a result cumulated net cash flows grow more slowly and the resulting SPP variations stronger, as it takes more periods to regain invested capital when net cash flows are lower.

The SPP would be less than 22 years (almost 50% less) if NG gas prices were not subsidized. In case of minimum total investment costs at 400 EUR/m² the resulting SPP drops by 32% to about 29 years.

5.4.3 Best Case Scenario

Whereas the sensitivity analysis varies only one parameter and holds all other parameters constant, a scenario analysis shows the impact of a combination of changed, but not varied, parameters (Crundwell, 2008, p. 281).

Chapter 5.4.1 showed that the reference case is not economically feasible without financial policy instruments. In the following, the economics of a SHIP investment is assessed based on optimistic assumptions of parameters within the selected ranges of the sensitivity analysis. Input parameters that can vary strongly depending on system concepts and temperature levels are investment costs, utilization rate, and system efficiency. Additionally, boiler efficiencies can be low. Furthermore, future annual energy price increases are assumed to increase at a maximum level (see Table 16).

Input parameter	Unit	Stationary	Concentrating
Annual energy price increase	%	10	
Specific total investment costs	EUR/m²	300	400
System efficiency	% of G	50	40
Utilization rate	% of Q_{sol}	100	
Boiler efficiency	%	75	

Table 16: Input Parameters of Best Case Scenario
Source: own illustration

[17] Energy price increases are assumed to increase annually at 7%.

Inflation rates have little impact, interest rates of private banks cannot be expected to be below 8%, and O&M costs were taken from different literature sources and correspond therefore to the assumptions of the reference case. The same holds for remaining input parameters.

The resulting cash flows for the four different best case scenarios are illustrated in Figure 30 to Figure 33, pp. 73f. in appendix. Only stationary technologies show a positive NPV without financial support and based on optimistic assumptions. Yet, the resulting SPP are above five years in all four best cases (see Table 17). As stated before, the SPP is not useful as a single investment criteria, because the cash inflows of the years after the SPP are not taken into account. This holds true especially for SHIP investments characterized by increasing future cash inflows due to expected energy price increases. However, surveys carried out within the GIZ project to select a suitable partner company for SHIP pilot plants have confirmed that the main economic decision criteria among potential partner companies is the maximum PP of five years. This severely impedes investment into SHIP when investment decisions are based solely on SPP.

Value	Unit	Replaced Fuel	Stationary	Concentrating
NPV	EUR	NG	25,819	-183,416
		FO	172,902	-69,656
IRR	%	NG	12.96	4.02
		FO	19.59	9.06
SPP	a	NG	19.71	16.40
		FO	8.23	12.84

Table 17: SPP, NPV, and IRR of Best Case Scenarios
Source: own illustration

5.5 Economics of SHIP with Financial Policy Instruments

The previous section showed that only under very optimistic assumptions could stationary SHIP investments be economically feasible. They are still not attractive for industries, however, due to high SPP. It is questionable if the assumed best cases exist and if they do, they represent only a small share of the technical potential. To introduce SHIP on a larger scale financial policy instruments are necessary to support the new technology. Several instruments have been presented in chapter three. In the following, the impact of selected instruments on the economics of the reference cases will be examined. The impact of financial instruments is evaluated from the perspective of both the industry and the Tunisian state.

5.5.1 Grants

Results of the sensitivity analysis showed that high up-front investment costs have a large impact on the SPP. Providing grants to for SHIP investments can contribute to reducing this barrier. Currently, grants are available at 30% of investment costs, capped at about 65 EUR/m² (see Table 7, p. 23). In case of FPC, the total grant would represent about 16.25%[18] of the total investment costs. The cap represents the gross specific public costs and does not consider the public savings arising from subsidized fuel savings. Calderoni et al. (2012) analyzed the economics of a SHIP plant using FPC for different grant levels. Their study did not consider future subsidy reductions and the authors proposed further analysis under the more realistic assumption of reduced future subsidies.

Assuming energy price increases as stated in Table 5, p. 18, subsidies for NG for industrial consumers will have been eliminated by 2028 and an energy tax would result in gradually increasing NG prices. For future public savings the time value needs to be taken into account by discounting them with a nominal discounting factor of 8.6%. This corresponds to a real discounting factor of 4%, since governments have lower profit interest than industries. The resulting specific public savings depend on the annual fuel savings of the SHIP plant. Assuming the reference SHIP plant using FPC, the NPV of specific subsidy savings are about 57 EUR/m². For ETC and concentrating technologies costs would be about 10 EUR/m² lower, because solar yields are smaller. Both technologies have similar solar yields, because the higher utilization rate of concentrating technologies compensates to some extent for their lower efficiencies (see Table 18 and exemplary calculation for FPC reference case in Table 38, p. 76 in appendix). Net specific public costs of current grants are only about 8 EUR/m² if NG is replaced. For FO replacement grants should be at a minimum around 200 EUR/m² depending on the solar yield of the technology. This grant corresponds to the NPV of specific public savings (see calculation in Table 39, p. 77 in appendix).

Under the current subsidy scheme reference SHIP investments are not economically feasible for NG, nor for FO (see Table 18 below and exemplary cash flow illustrated in Figure 34, p. 75 in appendix).

Realized SHIP plants listed in Table 9 and Table 10 have received grants up to 50% and were still subject to PP up to 10 years[19]. A 50% grant rate results in high net specific public costs that are probably not politically enforceable. Besides, SHIP investments replacing NG would still not be economically feasible, despite the high grant. Only SHIP plants using FPC and replacing FO show a positive NPV, but the SPP remains above the acceptable limit. For the same case, the state would have more public savings due to avoided FO subsidies than public costs (see Table 18).

[18] $\frac{65\ \mathrm{EUR/m^2}}{400\ \mathrm{EUR/m^2}}$

[19] Higher SPP might be accepted for marketing reasons.

Value	Unit	FPC	ETC	Conc.	FPC	ETC	Conc.
NG Grant	% of C_{inv}	16.25%	13%	9.3%		50%	
NPV	EUR	-182,179	-314,136	-565,860	-55,740	-140,868	-299,026
IRR	%	0.58%	-5.01%	-15.93%	6.55%	0.10%	-11.97%
SPP	a	19.25	28.09	>60	13.43	19.87	>60
Gross specific public costs	EUR/m²	65.0	65.0	65.1	200	250	350
NPV of specific public savings	EUR/m²	57.1	48.2	48.1	57.1	48.2	48.1
Net specific public costs	EUR/m²	7.9	16.8	17.0	142.9	201.8	301.9
FO Grant	% of C_{inv}	16.25%	13%	9.3%		50%	
NPV	EUR	-105,354	-249,262	-501,180	21,085	-75,994	-234,346
IRR	%	5.82%	-0.19%	-7.96%	13.53%	6.05%	-3.00%
SPP	a	14.01	20.25	34.90	9.54	13.81	24.55
Gross specific public costs	EUR/m²	65.0	65.0	65.1	200	250	350
NPV of specific public savings	EUR/m²	220.5	186.2	185.7	220.5	186.2	185.7
Net specific public costs	EUR/m²	-155.5	-121.2	-120.6	-20.5	63.8	164.3

Table 18: NPV, IRR, SPP and Specific Public Costs of Reference SHIP Investments with Current and 50% Grant Rate
Source: own illustration

5.5.2 Soft Loans

The sensitivity analysis showed that the impact of varying interest rates on SPP is small. If the soft loan offered by the World Bank[20] was available for financing a SHIP investment, loan repayments would be shifted resulting in even longer SPP than without soft loan, because the lower value of future loan repayments is not considered by the static method (see Figure 35, p. 75 in appendix). All three reference cases show negative NPV for both fuel options and are not economically feasible for applying soft loans.

5.5.3 Bonus Model

Bonus payments for every kilowatt hour of saved NG can compensate to some extent for low NG price and allow a reduction in planning risks associated with future price trends. Furthermore, it has the advantage over the grant that financial support is only granted for used SPH which encourages plant operators to maintain the plant. On the other hand, it requires heat metering and controls on the used SPH. In free energy markets this instrument is advantageous due to the independence of the state budget. For Tunisia this is not the case, because the Tunisian energy supplier, the STEG, is state-owned.

[20] interest rate: 5.5%, grace period: 3 years, repayment period: 12 years

The minimum amount of bonus paid by the Tunisian state should be the subsidized part of the NG mean cost price. This is the part saved by the state when no subsidized NG is consumed and is currently about 1.7 EUR cents/kWh (see chapter 4.2.2). Paying a fixed bonus of 1.5 EUR cents/kWh throughout the lifetime of a SHIP plant would cause a NPV of specific public of about 60 EUR/m² depending on the technology. But it is not sufficient for a profitable SHIP investment (see exemplary cash flow in Figure 36, p. 75 in appendix). Bonus payments of 4 EUR cents/kWh would be necessary to yield a positive NPV for FPC SHIP plants and a SPP below ten years. This results in high discounted specific public costs (see Table 19 and for details on calculation Table 40, p. 78 in appendix).

For FO replacement the subsidized portion is roughly 4.3 EUR cents/kWh. Therefore, industries using FO impose a higher burden on the state budget. A bonus payment of 3 EUR cents/kWh over 20 years yields a positive NPV for FPC SHIP plants. The resulting NPV is only slightly higher than for the same SHIP plants supported by a 50% grant. Public costs, however, amount to about 20 EUR/m² for the bonus payment and yield public savings of around 20 EUR/m² when applying the 50% grant rate. Bonus payments of 5 EUR cents/m² are not sufficient for economic feasibility of ETC and concentrating technologies. FPC SHIP plants show a positive NPV, but a SPP over five years.

Value	Unit	FPC	ETC	Conc.	FPC	ETC	Conc.
NG Bonus	EUR/kWh	0.015			0.04		
NPV	EUR	-145,604	-282,721	-544,784	16,818	-155,565	-408.039
IRR	%	4.2	-1.5	-9.3	12.6	4.9	-2.5
SPP	a	15.1	23.3	>60	9.4	14.2	40
NPV of specific public costs	EUR/m²	62.9	53.2	53	264.0	222.1	221.4
FO Bonus	EUR/kWh	0.03			0.05		
NPV	EUR	28,674	-145,553	-398,057	158,611	-35,828	-288,660
IRR	%	13.1	5.7	1.4	20.0	10.2	2.5
SPP	a	9.3	13.7	24.1	7.1	10.6	16.7
NPV of specific public costs	EUR/m²	19.6	16.5	16.5	179.6	151.7	151.2

Table 19: NPV, IRR, SPP and Specific Public Costs of Reference SHIP Investments with Bonus Payments
Source: own illustration

6 Summary and Conclusion

6.1 Recommendations for Future Policy

Current grants are not sufficient for economic feasible SHIP investments. The comparison of public costs with public savings showed that the current grant rate is very low. Grant rates above 50% can be justified for SHIP plants using FPC and replacing FO. For the other cases 50% grants cause high public costs without yielding an economically feasible SHIP investment.

Bonus payments can be a suitable instruments to compensate for low NG prices. The model has not been used in the heat market and Tunisian institutions do not have experiences with similar models, such as feed-in tariffs for electricity. Therefore acceptance for its introduction in the solar thermal market might be low.

A combination of both policy instruments should be considered and directed to the most promising industries and technologies. The results of the sensitivity analysis showed that the SPP varies strongly depending on system efficiencies and utilization rate. Probably only very few industries similar to the best case scenario exist, but their potential should be tapped at first. Identifying the most promising industrial companies could be done in the framework of the obligated periodic energy audits by gathering additional information or evaluating existing information. Industries with processes on low temperature levels, but with high and consistent heat demands are the most promising. Industrial companies using FO should be of priority, because FO replacement yields both high fuel cost savings and public savings. Furthermore, the economic assessment showed that stationary technologies are still more cost-efficient, than concentrating technologies, despite the high DNI values in Tunisia. Moreover, FPC can be manufactured locally. Grants or bonus payments should therefore be directed to SHIP investments for industries with promising demand profiles, using stationary technologies, and replacing the consumption of FO. The food and beverage sector is especially promising, since the majority of reported SHIP plants have been realized in this sector. Therefore, there is more experience with process integration and approved concepts exist.

Funding for pilot plants using concentrating technologies should also be available to gain more experience in this field.

The main barrier of SHIP investments, however, is seen in the long SPP due to lifetimes of 20 years and high-upfront investment. The best case scenario and economics with financial support showed that even profitable SHIP investments would be neglected by industries due to SPP over five years. Pilot plants can show the reliability of the new technology, but planning risks remain, especially during the Tunisian period of transition. ESCOs might accept higher SPP, since they are familiar with the technology. Local manufacturers of stationary collectors could act as ESCOs. In addition, non-financial instruments, such as awareness-raising campaigns among industries contribute to reduce skepticism towards SHIP and can result in higher acceptable SPP.

6.2 Conclusion

The economic assessment of SHIP investments under moderate assumptions showed that despite the large technical potential, the economic potential of SHIP is small under current framework conditions in Tunisia. Neither stationary, nor concentrating technologies are economically feasible. Although, replacing fuel oil yields higher fuel cost savings than replacing NG, the investment is not profitable.

The sensitivity analysis showed that energy prices and system costs have a strong impact on the SPP. System costs, system efficiencies, and the utilization rate can vary widely among different SHIP plants. Under optimistic assumptions concerning the mentioned input parameters, investments in SHIP using stationary technologies show a positive NPV, but a SPP above the maximum of five years. As a result of elevated O&M costs and lower solar yields in comparison to stationary collectors, concentrating technologies are not economically feasible in any scenario. Their technical potential, however, is larger, since SPH can be provided at higher temperature levels.

Grant rates can reduce the barrier of high upfront costs. The level of the grant rate should be set on the basis of public savings due to avoided conventional energy subsidies. Assuming a maximum grant rate of 50% is not sufficient if NG is replaced. Only stationary SHIP plants replacing FO yield a low positive NPV, but a SPP of almost ten years.

Highly subsidized energy prices reduce fuel cost savings and represent a barrier to SHIP investment. The bonus model allows to shift subsidies from conventional to renewable energies. But public costs for the bonus model are higher in comparison to grants.

Despite profitability shown by positive NPV and high IRR, industries would neglect SHIP investments due to SPP above five years. This is seen as the main barrier to SHIP investments in Tunisia and further research should evaluate the possible role of ESCOs in overcoming this barrier.

A special focus should be on stationary technologies, due to local production, low system costs, more experience, and higher solar yields. Industries consuming fuel oil have the highest potential and it is recommended to assess their suitability within the obligated energy audits.

Without financial policy instruments, solar thermal markets for industrial processes are unlikely to develop. The future development of SHIP in Tunisia depends to some extent on future system cost reduction, but to most extent on future energy policy of the Tunisian government and the political will to shift conventional energy subsidies towards renewable energies.

7 Appendix

A Solar Thermal Collectors Schemes

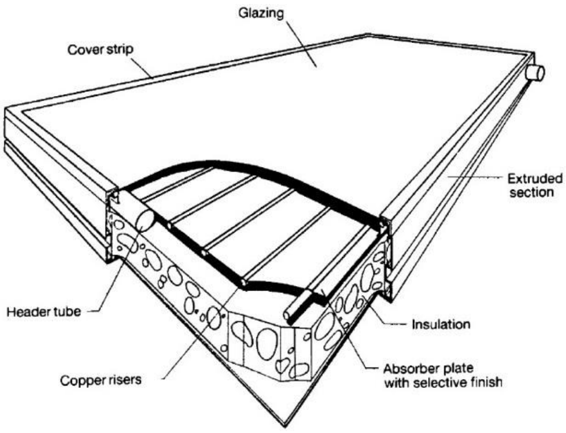

Figure 17: FPC Scheme
Source: Kalogirou (2004, p. 241), adapted by author

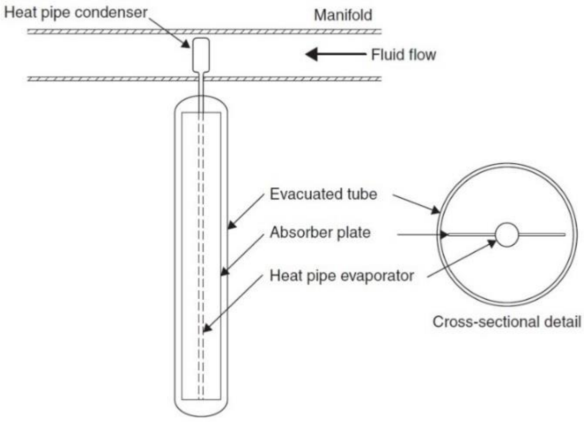

Figure 18: ETC Scheme
Source: Kalogirou (2014, p. 137)

15 to 20 evacuated tubes are parallel aligned and connected to the header pipe at the upper end forming one collector.

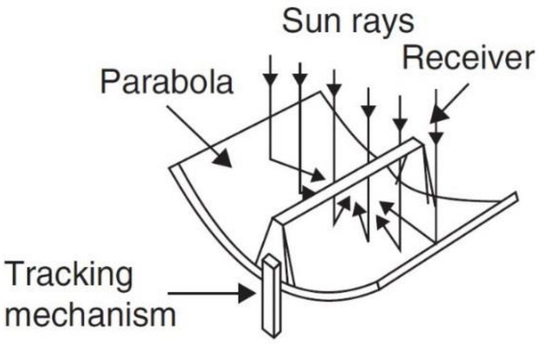

Figure 19: PTC Scheme
Source: Kalogirou (2004, p. 248)

Parabolic mirrors are aligned side by side forming a parabolic trough which reflects sun rays onto the receiver inside a glass tube. The tracking mechanism assures that the mirrors face the sun throughout the day.

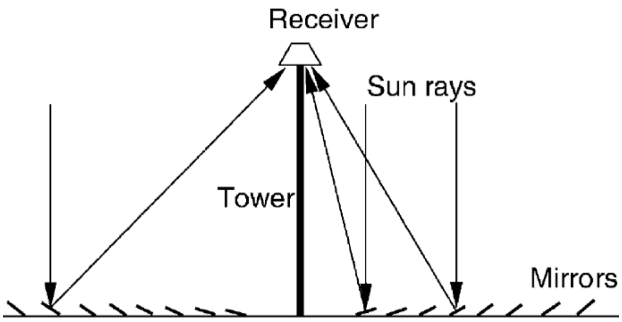

Figure 20: LFR Scheme
Source: Kalogirou (2004, p. 250)

LFRs form a broken-up parabolic trough by using a field of linear mirrors that concentrate sun rays on a receiver mounted on the tower. Each flat mirror strip is connected to the tracking system and turned according to the position of the sun. (Xie et al., 2011, p. 2592)

B Temperature Ranges of Suitable Processes

Industrial Sector	Process	Temperature Level in °C
Several sectors	Make-up water	20-110
	Preheating	20-100
	Washing	30-90
Chemical	Biochemical reaction	25-55
	Distillation	100-200
	Compression	110-170
	Cooking	85-110
	Thickening	130-140
Food and Beverages	Blanching	60-90
	Scalding	45-90
	Evaporating	40-130
	Cooking	70-120
	Pasteurization	60-145
	Smoking	20-85
	Cleaning	60-90
	Sterilization	100-140
	Tempering	100-140
	Drying	40-200
	Washing	35-80
Paper	Bleaching	40-150
	De-Inking	50-70
	Cooking	110-180
	Drying	95-200
Textiles	Bleaching	40-100
	Coloring	40-130
	Drying	60-105
	Washing	50-100

Table 20: Industrial Sectors and Processes with Temperature Levels Suitable for SHIP
Source: own illustration; Lauterbach et al. (2011a, p. 2)

C System Concepts

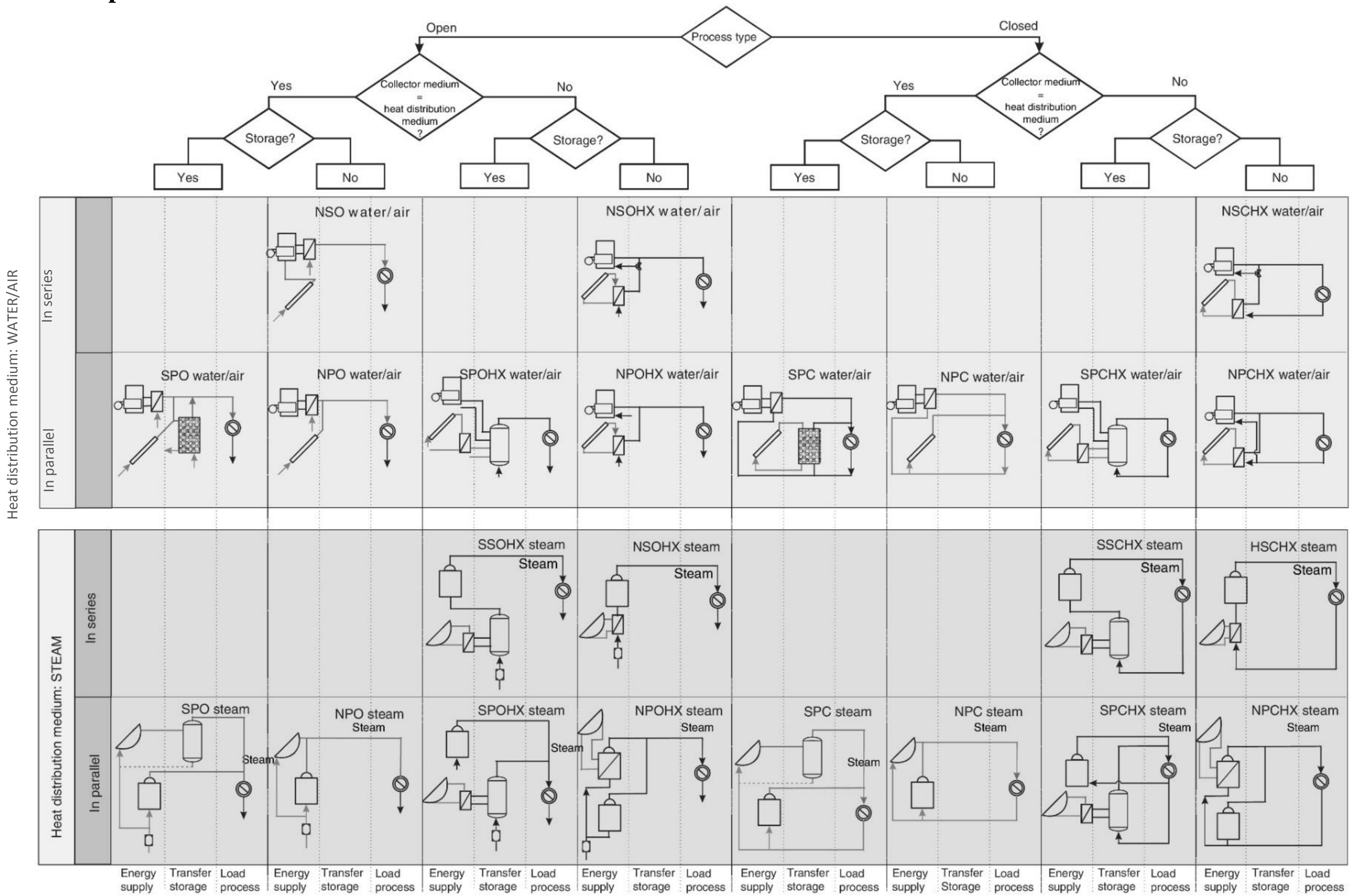

Figure 21: Classification of SHIP System Concepts
Source: Battisti et al. (2007), adapted by author

D Key Facts on Energy Situation in Tunisia

	Unit	2011
Electricity generation	GWh	**15247**
Gas	%	98.9
Oil	%	0.1
Wind	%	0.7
Hydro	%	0.3
Electricity consumption per capita	MWh/capita	1.3
Installed generating capacity	MW	**4024**
STEG	MW	**3526**
Steam plant (gas-fired)	% of total capacity	27.1
Combined cycle	% of total capacity	19.6
Gas turbine	% of total capacity	38.1
Hydro	% of total capacity	1.5
Wind park	% of total capacity	1.3
Independent Power Producers	MW	**498**

Table 21: Electricity Generation and Generating Capacity, Tunisia 2011
Source: STEG (2011)[21]

[21] It is the latest published annual report. The share of renewables is probably slightly higher by now.

Indicator	Unit	2010
Total Energy Production	Mtoe	**8.1**
Natural gas	%	33.3
Crude oil	%	49.4
Biofuels and waste	%	17.3
Imports	Mtoe	**5.7**
Natural gas	%	29.1
Crude oil	%	3.4
Oil products	%	67.5
Exports	Mtoe	**-4.0**
Crude oil	%	96.2
Oil products	%	3.8
Bunkers and Stock	Mtoe	**-0.1**
TPES	Mtoe	**9.7**
Deficit (TPES - Production)	Mtoe	**1.6**
Natural gas	%	45.3
Crude oil	%	4.3
Oil products	%	35.8
Biofuels and waste	%	14.4
Hydro and Wind	%	0.2
Total final consumption (excluding demand of electricity plants, statistical differences, losses, energy industry own use & others)	Mtoe	**7.2**
Industry	%	27.8
Heat (oil products and natural gas)	%	78.0
Electricity	%	22.0
Transport	%	28.0
Residential	%	27.5
Other	%	16.7
Energy Intensity (TPES/GDP)	toe/ 1000 USD	**0.22**

Table 22: Energy Balance Tunisia 2010
Source: IEA (2011)

E Calculations of Input Parameters

Year	Inflation	Source	Annual inflation rate	
2004	3.63	World Bank	**4.16**	
2005	2.02			
2006	4.49			
2007	3.42			
2008	4.92			
2009	3.52			
2010	4.42			
2011	3.61			
2012	5.50			
2013	6.09			
Aug 14	6.07	Trading Economics	**6.07**	
2015	5.62		**4.98**	**4.39**
2016	5.30	linear interpolation		
2017	4.98			
2018	4.65			
2019	4.33			
2020	4.01	Trading Economics	**4.19**	
2021	4.05	linear interpolation		
2022	4.09			
2023	4.12			
2024	4.16			
2025	4.20			
2026	4.24			
2027	4.28			
2028	4.31			
2029	4.35			
2030	4.39	Trading Economics		
2031	4.16	World Bank, average 2004-2013		
2032	4.16			
2033	4.16			
2034	4.16			

Table 23: Calculation Average Annual Inflation Rates 2004-2034
Source: World Bank (2013), Trading Economics (2014)

	Day		Summer Peak at		Evening Peak		Night			
	from	to	from	to	from	to	from	to		
Winter (September to May)	07:00	18:00	-	-	18:00	21:00	21:00	07:00	TND/EUR	2.32
Summer (June to August)	06:30	08:30	08:30	13:30	19:00	22:00	22:00	06:30		
	13:30	19:00								
Price in mill/kWh	**152**		**238**		**218**		**115**			
Share for SHIP	88.48%		10.73%		0.07%		0.71%			
Average price for SHIP in EUR cents/kWh			**6.94**							

	January	February	March	April	May	June	July	August	September	October	November	December
Sunrise Tunis (mid month)	07:29	07:05	06:28	05:43	05:09	04:58	05:10	05:35	06:00	06:25	06:56	07:23
Sunset Tunis (mid month)	17:28	18:01	18:27	18:55	19:21	19:41	19:39	19:11	18:28	17:44	17:11	17:05
SPH generation start*	08:44	08:20	07:43	06:58	06:24	06:13	06:25	06:50	07:15	07:40	08:11	08:38
SPH generation stop*	16:13	16:46	17:12	17:40	18:06	18:26	18:24	17:56	17:13	16:29	15:56	15:50
Day	07:29	08:26	09:29	10:40	11:00	06:56	06:54	06:06	09:58	08:49	07:45	07:12
Summer Peak	0	0	0	0	0	05:00	05:00	05:00	0	0	0	0
Evening Peak	0	0	0	0	00:06	0	0	0	0	0	0	0
Night	0	0	0	00:02	00:36	00:17	00:05	0	0	0	0	0
Sum	07:29	08:26	09:29	10:42	11:42	12:13	11:59	11:06	09:58	08:49	07:45	07:12
Proportions												
Day	100%	100%	100%	100%	94%	57%	58%	55%	100%	100%	100%	100%
Summer Peak	0%	0%	0%	0%	0%	41%	42%	45%	0%	0%	0%	0%
Evening Peak	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%
Night	0%	0%	0%	0.3%	5%	2%	1%	0%	0%	0%	0%	0%
Days/Month	31	28	31	30	31	30	31	31	30	31	30	31
Day	31.00	28.00	31.00	29.91	29.15	17.03	17.85	17.04	30.00	31.00	30.00	31.00
Summer Peak	0.00	0.00	0.00	0.00	0.00	12.28	12.93	13.96	0.00	0.00	0.00	0.00
Evening Peak	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Night	0.00	0.00	0.00	0.09	1.59	0.70	0.22	0.00	0.00	0.00	0.00	0.00

***SHIP Plant Beva, July, sunny day**		
SPH generation starts at 7:30 (about 1:45 after sunrise)	sunrise (Zürich) 15.07.: 05:43	
solar generation stops at 20:15 (about 1:00 before sunset)	sunset (Zürich) 15.07: 21:20	
Difference between the two time differences due to local differences between Beva and Zürich		
Conclusion: solar generation starts and stops after/before sunrise/sunset about:		**01:15**

Table 24: Calculation of Electricity Price for SHIP Plants

Source: STEG (2014b), STEG (2014c), Timezone Guide (2014), Minder (2014, p. 18), OANDA (2014)

	Price in TND/t	Price in TND/kWh	Price in EUR cents/kWh	Price in EUR cents/kWh (incl. VAT)
Fuel oil no. 2	510	0.0449	**1.94**	2.28

Conversion	
Net calorific value of fuel oil in MJ/kg	40.87
MJ/kWh	3.6
TND/EUR	2.32
VAT	18%

Table 25: Calculation of FO Price
Source: MIEM, Huffington Post Maghreb (2014), Staffell (2011)

Pressure	Consumption					Price				
	th/month		th/h			Tariff in mill/th	Tariff in mill/kWh	Average in mill/kWh	Average in EUR cents/kWh	Average in EUR cents/kWh (incl. VAT)
Medium			1000	to	4000	37.6	32.34	32.12	1.385	1.634
			6000	to	30000	37.1	31.91			
High*			10000	to	30000	32.0				
	<	20000000		<	30000	35.0				
	>	20000000		<	30000	47.5				

*only 23 industries obtain high pressure NG: those are power plants and heavy industries, not relevant for SHIP

Conversions	
th/kWh	0.86005065
mill/EUR cent	23.2
VAT	18%

Table 26: Calculation of NG Price for Industries Suitable for SHIP
Source: STEG (2014d), STEG (2014e), STEG (2014a)

	2006	2007	2008	2009	2010	2011	2012*	2013*	2014**	annual increase	Source
Mean Retail Price NG in current TND/toe (excl. VAT)	170.1	177.1	248	272.7	288.6	305.3	309.8	341.7	363.9	10.0%	ONE
Mean Retail Price Fuel oil in current TND/ton (excl. VAT)	265	310	370	380	420	-	480	-	510	8.5%	Ali Ben Hmid***

* for NG only, estimations by ONE ** for NG only, see calculations mean retail price 2014
*** Tunisian energy expert who researched past price increases based on preses releases due to lack of official statistics

Table 27: Historic Retail Prices of NG and Fuel Oil
Source: ONE, Ali Ben Hmid, Huffington Post Maghreb (2014)

Tariff	Pressure Level	Consumption					Price				Demand 2013 (estimation by STEG)		Mean retail price	
		th/month		th/h			mill/th	Average in mill/th	Average in mill/kWh	Average in EUR cents/kWh (excl. VAT)	in ktoe	Share in %	in EUR cents/kWh (excl. VAT)	in TND/toe (excl. VAT)
Residential customers, May 2014	Low 1	<	300	50	to	100	23.5	33.90	29.16	1.26	497	34.28%	**1.35**	**363.91**
		300 to	600				29.5							
		600 to	1500				36.0							
		>	1500				42.2							
	Low 2			160	to	8000	38.3							
Industrial customers, May 2014	Medium			1000	to	4000	37.6	37.35	32.12	1.38	572	39.45%		
				6000	to	30000	37.1							
	High			10000	to	30000	32.0	38.17	32.83	1.41	381	26.28%		
		<	20000000		<	30000	35.0							
		>	20000000		<	30000	47.5							
											1450.00			

Conversions	
th/kWh	0.86005065
mill/EUR cent	23.2
VAT	18%
kWh/toe	11630

Table 28: Estimation of Mean Retail Price in 2014
Source: STEG (2014f), STEG (2014e), STEG (2014d), STEG (2014a)

	Fossil fuel import prices by scenario in USD/MBtu								Source
Fuel	**Scenario**	unit	**2012**	**2015**	**2020**	**2025**	**2030**	**2035**	
European NG import price	**New policy**	2012 USD/Mbtu	11.7	n.a.	11.9	12	12.3	12.7	WEO 2013
	rate of change	%/a			0.21%	0.17%	0.50%	0.64%	
	Current policy	2012 USD/Mbtu	11.7	n.a.	12.4	12.9	13.4	14	
	rate of change	%/a			0.73%	0.79%	0.76%	0.88%	
	450	2012 USD/Mbtu	11.7	n.a.	11.5	11	10.2	9.5	
	rate of change	%/a			-0.22%	-0.89%	-1.50%	-1.41%	
Tunisian NG price	**Reference**	2010 EUR/GJ	n.a.	7.23	8.08	8.39	8.69	9	Wuppertal Institut
	rate of change	%/a			2.25%	0.76%	0.71%	0.70%	
	High	2010 EUR/GJ	n.a.	10.7	12.64	13.73	14.72	15.2	
	rate of change	%/a			3.39%	1.67%	1.40%	0.64%	
	Low	2010 EUR/GJ	n.a.	5.94	5.72	5.49	5.26	5.02	
	rate of change	%/a			-0.75%	-0.82%	-0.85%	-0.93%	
IEA crude oil imports	**New policy**	2012 USD/barrel	109	n.a.	113	116	121	128	WEO 2013
	rate of change	%/a			0.45%	0.53%	0.85%	1.13%	
Tunisian price crude oil	**Reference**	2010 EUR/GJ	n.a.	12.29	12.98	13.66	14.35	15.06	Wuppertal Institut
	rate of change	%/a			1.10%	1.03%	0.99%	0.97%	

The new policy scenario is considered to reflect the most realistic assumptions. Whereas, the current policy scenario assumes inaction of governments, scenario 450 assumes high commitment of governments in reducing fossil fuel consumption.

Table 29: Fossil Fuel Import Prices by Scenario
Source: IEA (2013, p. 48), Lechtenböhmer et al. (2012, pp. 20 ff.)

T_{op}	collector efficiency	specific collector yield	thermal losses	System efficiency	specific solar yield	GHI	G_{tilt}
°C	%	kWh/m²/a	% of collector yield	%	kWh/m²/a	kWh/m²/a	kWh/m²/a
80	49%	631	15%	**41.6%**	536.35		1288.45

Table 30: System Efficiency using ETC
Source: Fichtner (2013, p. 31), solar irradiation of Würzburg from PVGIS

F Review of Studies on SHIP Potential

Author (Title)	page	Country or Region	Tempe-ratures of pro-cesses	Final Energy Consumption	Total Heat Demand*		Theoretical Potential / Total low+med heat*		Technical Potential/Solar Heat*				
				in ktoe/a	in ktoe/a	in ktoe/a	in ktoe/a	**share** of total heat	in ktoe/a	**share** of low+med heat	**share** of total heat	**share** of total heat	**share** of final energy
Schweiger, 2001 (POSHIP)	138-142, 151	Iberian Peninsula	< 160 °C	91527.00		13927.86	3232.67	**23.21%**	499.05	**15.44%**	**3.58%**		**0.55%**
Müller et al., 2004 (PROMISE)	34, 149, 153	Austria,	< 250 °C	6305.53			883.73		128.98	**14.59%**			**2.05%**
Vannoni et al., 2008	8	EU 25	not defined	310356.36	164349.86				6167.00			**3.75%**	**1.99%**
Lauterbach et al., 2011	19	Germany	< 250 °C		43731.73	18383.49	11177.99	**60.80%**	1341.36	**12.00%**	**7.30%**	**3.07%**	
Reiners, 2011	42-54	Tunisia, Mediter-ranean	< 250 °C				376.61						
Amous, 2013		Tunisia	< 250 °C	637.54	1627.60	480.35	318.92	**66.39%**	31.89	**10.00%**	**6.64%**	**1.96%**	**5.00%**
				of selected industry (see next page)				*incl. space heating and sanitary hot water when relevant (not in Tunisia)					
				of entire industry									

Table 31: Comparison of Findings of Different Studies on Potential for SHIP

Source: own illustration; Schweiger et al. (2001), Müller et al. (2004), Vannoni et al. (2008), Lauterbach et al. (2011b), Reiners (2011), Amous (2013)

Author (Title)	**Country or Region**	**Tempe-ratures of processes**	**Selected industries**										
			Food and beverage	Chemical	Textiles	Building materials	Paper	Plastics	Timber by-products	Cleaning/ Washing	Auto-mobile	Transport equipment	Metal treatment
Schweiger, 2001 (POSHIP)	Iberian Peninsula	< 160 °C	x	x	x		x				x		
Kalogirou, 2003		< 240 °C	x	x	x	x (brick-making)	x	x	x				
Müller et al., 2004 (PROMISE)	Austria,	< 250 °C	x	x	x (but no leather)	x (precast concrete)		x					
ESTIF, 2006		< 100 °C	x	x	x					x			
Schnitzer et al., 2007	Austria	< 100 °C	x	x	x	x		x					
Vannoni et al., 2008	EU 25	not defined	x	x	x			x				x	x
Lauterbach et al., 2011	Germany	< 250 °C	x	x	x		x	x	x (very little)		x		x
Reiners, 2011	Tunisia, Mediterranean	< 250 °C	x	x	x		x	x					
Amous, 2013	Tunisia	< 250 °C	x	x	x		x						

Table 32: Selected Industrial Sectors by Different Studies on Potential for SHIP

Source: own illustration; Schweiger et al. (2001), Kalogirou (2003), Müller et al. (2004), ESTIF (2006), Vannoni et al. (2008), Lauterbach et al. (2011b), Reiners (2011), Amous (2013)

G Ministry of Industry, Departments and Public Utilities

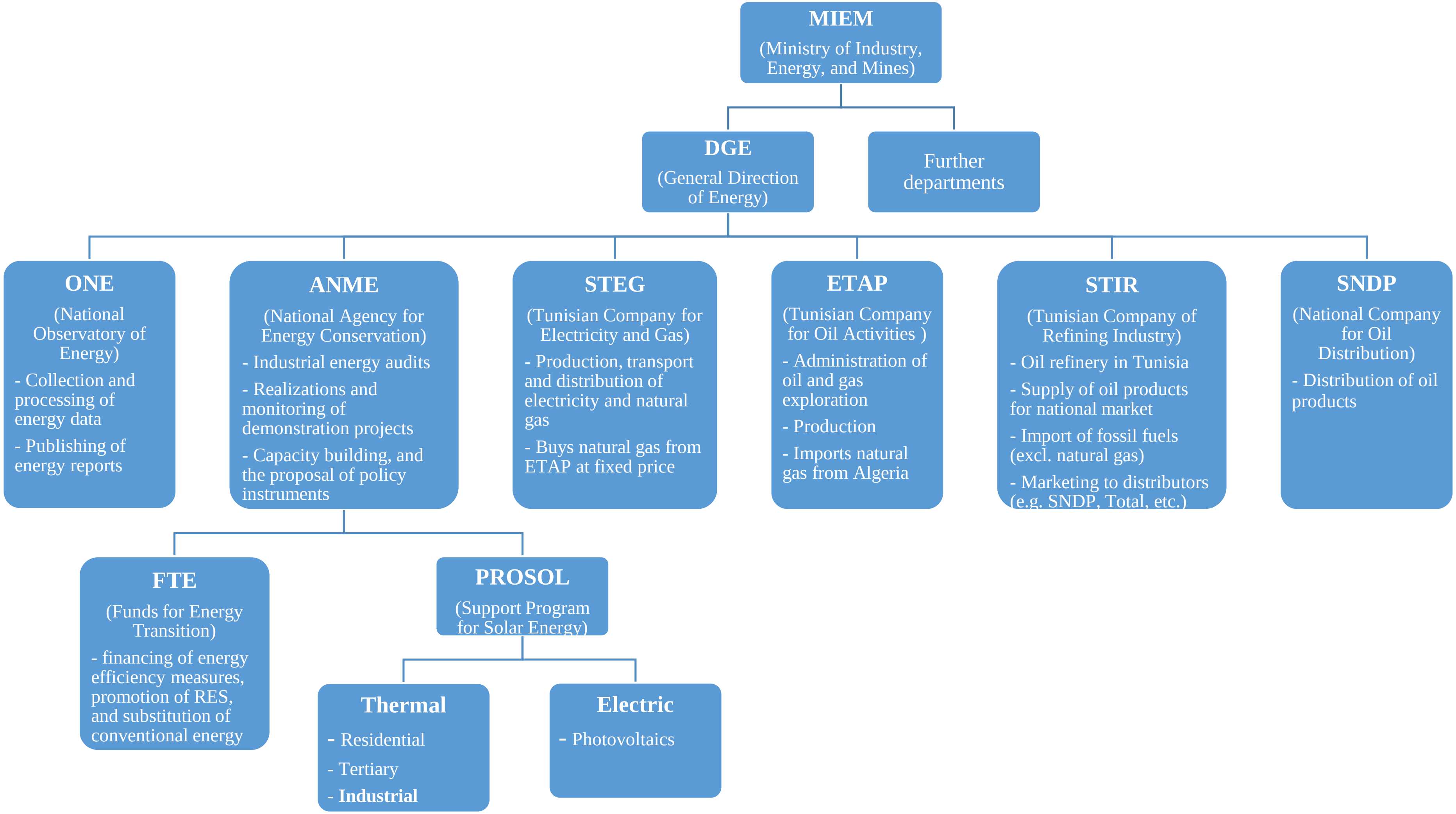

Figure 22: Organigram of Relevant Departments of the Ministry of Industry, Energy and Mines
Source: own illustration; Lechtenböhmer et al. (2012, p. 111), (MIEM, 2014)

H Estimated Future Trends of NG Subsidies

	Mean cost price in EUR cents/kWh	**Industrial retail price (excl. VAT)** in EUR cents/kWh	**Total subsidies** in EUR cents/kWh
Annual increase in %	1%	10%	
2012	3.07		
2013	3.10		
2014	3.13	1.38	1.75
2015	3.16	1.52	1.65
2016	3.19	1.67	1.52
2017	3.23	1.84	1.39
2018	3.26	2.02	1.24
2019	3.29	2.22	1.07
2020	3.32	2.44	0.88
2021	3.36	2.69	0.67
2022	3.39	2.96	0.43
2023	3.43	3.25	0.17
2024	3.46	3.58	-0.12
2025	3.49	3.94	-0.44
2026	3.53	4.33	-0.80
2027	3.56	4.76	-1.20
2028	3.60	5.24	-1.64
2029	3.64	5.76	-2.13
2030	3.67	6.34	-2.67
2031	3.71	6.98	-3.27
2032	3.75	7.67	-3.93
2033	3.78	8.44	-4.66
2034	3.82	9.28	-5.46

Table 33: Future Trend Mean Cost Price, Industrial Retail Price, and Total Subsidies for annual NG increase by 10%; 2014-2034
Source: own illustration; assumptions based on
Table 4: Energy Prices for Industries, p. 15
Figure 10: NG: Mean Cost Price, Industrial Retail Price, and Total Subsidies; Tunisia, 2012, p. 17
Table 5: Estimated Annual Energy Price Increases; Tunisia 2015-2035, p. 18

I Tool for Economic Assessment

Input Parameter	Unit	FPC	ETC	Conc
Aperture Area	m²	1000		
Life time	a	20		
Real discounting factor	%	7%		
Inflation	%	4.4%		
Nominal disounting factor	%	11.71%		
Electricity	EUR/kWh	0.0819		
Replaced Fuel	EUR/kWh	0.0163		
annual increase 1	%/a	10.0%		
increase 1 until	a	6		
annual increase 2	%/a	5.0%		
Bonus Model	EUR/kWh of S_{fuel}	0.000	0.000	0.000
until (including)	a	20		
Real discounting factor	%	4%		
Nominal discounting factor	%	8.58%		
Cash outflows				
Specific total investment costs	EUR/m²	400	500	700
Total investment costs	EUR	400,000	500,000	700,000
Grant rate	% of C_{inv}	0.00%	0.0%	0.0%
Specific public costs	EUR/m²	0.00	0.00	0.00
Total investment costs reduced by grant	EUR	400,000	500,000	700,000
Equity ratio	% of $C_{inv,red}$	30%		
Equity	EUR	120,000	150,000	210,000
Loan ratio	%	70%		
Amount	EUR	280000	350000	490000
i	%	8.0%		
grace period	a	0		
repayment period	a	5		
Annuity factor	%	25.05%		
Annuity	EUR/a	70127.81	87659.76	122723.66
O&M costs	% of C_{inv}	1.0%	1.0%	1.5%
annual increase	%/a	0.50%	0.50%	0.50%
Consumption costs	% of Q_{usol}	2.0%	2.0%	2.5%
Cash inflow				
Irradiation (G_{tilt} or DNI)	kWh/m²/a	2078	2078	2009
System Efficiency	% of Irradiation	45%	38%	33%
annual degradation	%/a	0.50%		
Specific solar yield	kWh/m²/a	935.10	789.64	662.97
Solar yield	kWh/a	935,100	789,640	662,970
Utilization rate	% of Q_{sol}	80%	80%	95%
Useful solar yield	kWh/a	748,080	631,712	629,822
Boiler efficiency	%	85%		
Fuel savings	kWh/a	880,094	743,191	740,966
Cash inflow	EUR/a	14,346	12,114	12,078
Economics				
NPV	EUR	- 243,057	- 375,014	- 626,831
IRR	%	-1.18%	-6.17%	-16.55%
SPP [Recalculate]	a	9.41	23.27	>60

Table 34: Section for Input Parameters of Tool for Economic Assessment

Source: own illustration

t	Cash Outflows						Cash Inflows				Economics		
	Equity	Annuity	O&M	Consump-tion	Total	change in %	Annual useful solar yield	Annual fuel savings	Annuel fuel cost savings	change in %	Net cash flows	Static cumulated cash flows	PV
0	210,000				210,000						- 210,000	- 210,000	- 210,000
1		122,724	10,962	1,419	135,104	-35.66%	629,822	740,966	13,286		- 121,819	- 331,819	- 109,051
2		122,724	11,502	1,560	135,786	0.50%	626,672	737,262	14,541	9.45%	- 121,245	- 453,063	- 97,161
3		122,724	12,068	1,716	136,508	0.53%	623,539	733,575	15,915	9.45%	- 120,593	- 573,656	- 86,510
4		122,724	12,662	1,888	137,273	0.56%	620,421	729,907	17,419	9.45%	- 119,854	- 693,510	- 76,969
5		122,724	13,285	2,077	138,085	0.59%	617,319	726,258	19,065	9.45%	- 119,020	- 812,530	- 68,423
6		-	13,939	2,285	16,223	-88.25%	614,233	722,627	20,867	9.45%	4,644	- 807,886	2,390
7		-	14,625	2,399	17,024	4.93%	611,161	719,013	21,801	4.48%	4,777	- 803,109	2,201
8		-	15,345	2,519	17,863	4.93%	608,106	715,418	22,776	4.48%	4,913	- 798,196	2,026
9		-	16,100	2,645	18,744	4.93%	605,065	711,841	23,795	4.48%	5,051	- 793,145	1,865
10		-	16,892	2,777	19,669	4.93%	602,040	708,282	24,860	4.47%	5,191	- 787,954	1,716
11		-	17,724	2,916	20,639	4.93%	599,030	704,741	25,973	4.48%	5,333	- 782,621	1,578
12		-	18,596	3,061	21,658	4.93%	596,034	701,217	27,135	4.47%	5,478	- 777,143	1,451
13		-	19,511	3,215	22,726	4.93%	593,054	697,711	28,349	4.48%	5,623	- 771,520	1,333
14		-	20,472	3,375	23,847	4.93%	590,089	694,222	29,618	4.47%	5,771	- 765,749	1,225
15		-	21,479	3,544	25,023	4.93%	587,139	690,751	30,943	4.48%	5,920	- 759,829	1,125
16		-	22,537	3,721	26,258	4.93%	584,203	687,298	32,328	4.48%	6,070	- 753,758	1,032
17		-	23,646	3,907	27,553	4.93%	581,282	683,861	33,775	4.48%	6,222	- 747,537	947
18		-	24,810	4,103	28,912	4.93%	578,375	680,442	35,286	4.47%	6,374	- 741,163	869
19		-	26,031	4,308	30,339	4.93%	575,484	677,040	36,865	4.48%	6,527	- 734,636	796
20		-	27,312	4,523	31,835	4.93%	572,606	673,654	38,515	4.47%	6,680	- 727,956	730

Table 35: Interim Results of Reference Case Using Concentrating Technologies; Replaced Fuel: NG

Source: own illustration

J Cash Flows of Reference SHIP Investment for NG Replacement

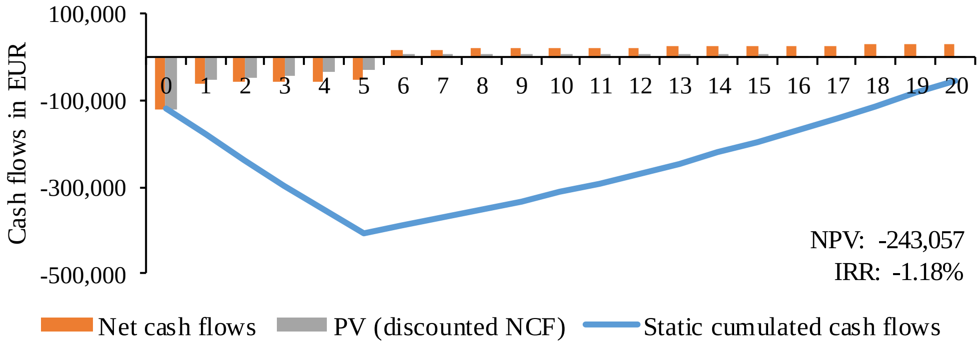

Figure 23: Cash Flows of Reference SHIP Investment Using FPC; Replaced Fuel: NG
Source: own illustration

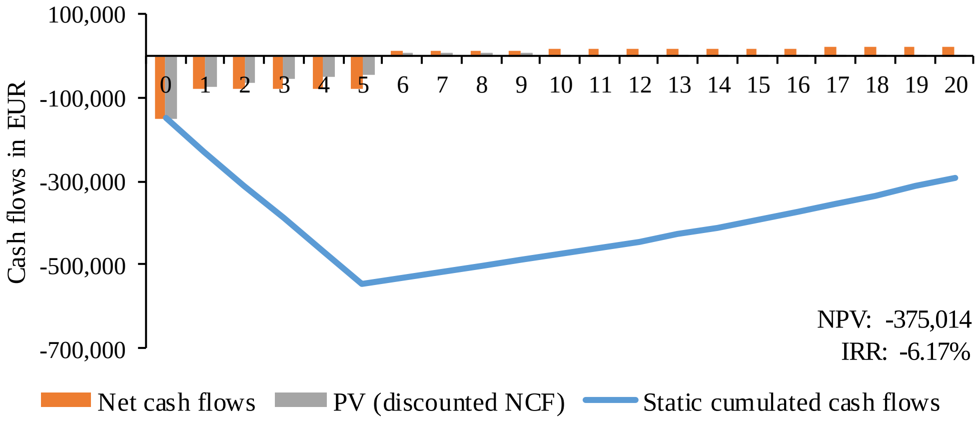

Figure 24: Cash Flows of Reference SHIP Investment Using ETC; Replaced Fuel: NG
Source: own illustration

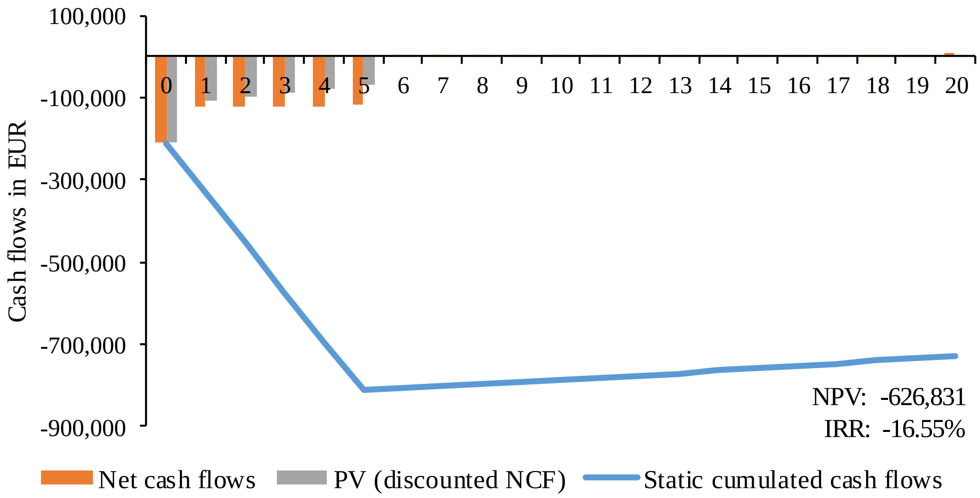

Figure 25: Cash Flows of Reference SHIP Investment Using Concentrating Technologies; Replaced Fuel: NG
Source: own illustration

K Cash Flows of Reference SHIP Investment for FO Replacement

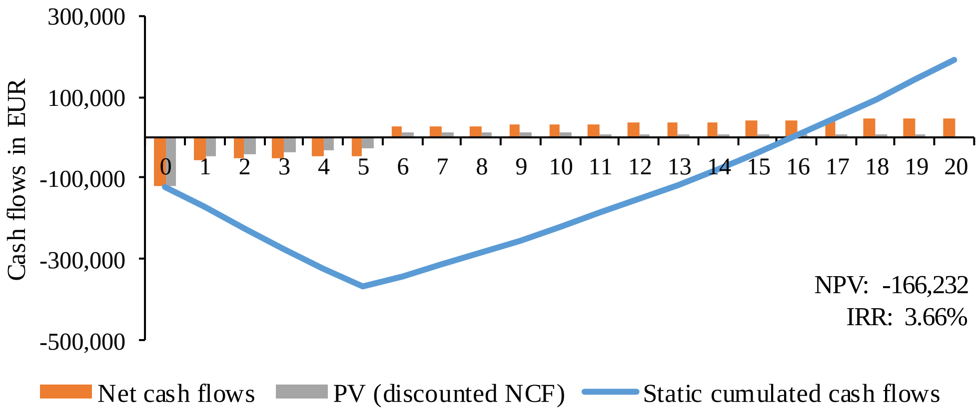

Figure 26: Cash Flows of Reference SHIP Investment Using FPC; Replaced Fuel: FO
Source: own illustration

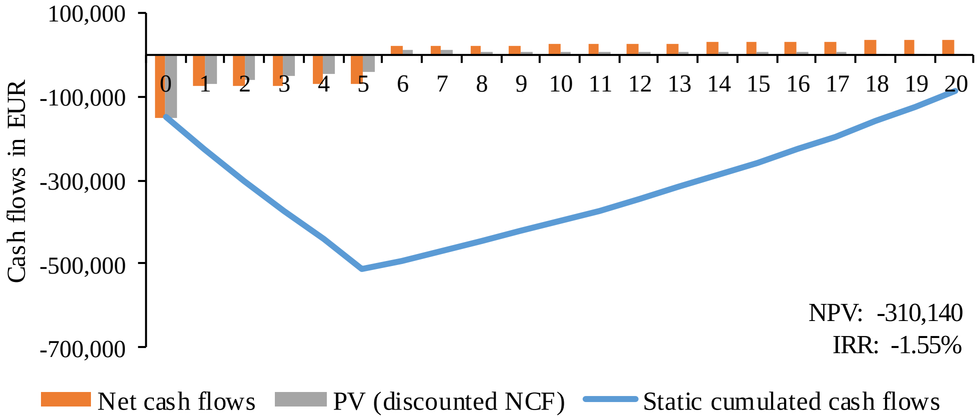

Figure 27: Cash Flows of Reference SHIP Investment Using ETC; Replaced Fuel: FO
Source: own illustration

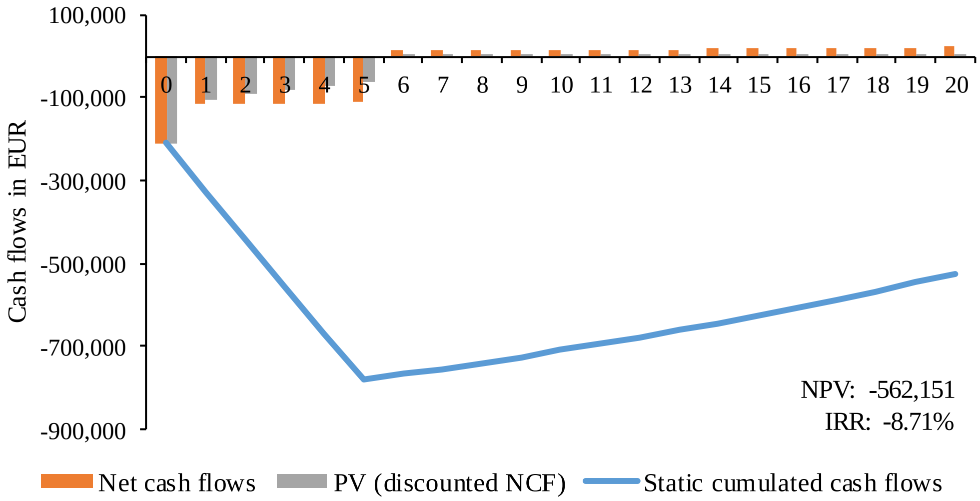

Figure 28: Cash Flows of Reference SHIP Investment Using Concentrating Technologies; Replaced Fuel: FO
Source: own illustration

L Sensitivity Analysis

Change of Input Parameter in %		-50%	-45%	-40%	-35%	-30%	-25%	-20%	-15%	-10%	-5%	0%	5%	10%	15%	20%	25%	30%
Annual inflation rate	abs. change of SPP in a	24.3	24.4	24.5	24.6	24.7	24.8	25.0	25.1	25.3	25.4	25.6	25.8	26.0	26.2	26.4	26.7	26.9
	rel. change of SPP in %	-5.2%	-4.8%	-4.4%	-3.9%	-3.5%	-3.0%	-2.4%	-1.9%	-1.3%	-0.7%	0.0%	0.7%	1.5%	2.3%	3.2%	4.1%	5.2%
Natural gas price	abs. change of SPP in a											25.6	24.7	23.8	23.0	22.3	21.6	21.0
	rel. change of SPP in %											0.0%	-3.6%	-6.9%	-10.0%	-12.8%	-15.5%	-17.9%
Annual energy price increase	abs. change of SPP in a		44.0	40.3	37.2	34.5	32.3	30.5	29.0	27.7	26.6	25.6	24.7	23.9	23.1	22.5	21.8	21.3
	rel. change of SPP in %		72.0%	57.6%	45.2%	34.7%	26.1%	19.2%	13.3%	8.3%	3.9%	0.0%	-3.5%	-6.6%	-9.5%	-12.2%	-14.6%	-16.9%
Specific total investment cost	abs. change of SPP in a					20.0	21.0	21.9	22.9	23.8	24.7	25.6	26.4	27.3	28.1	28.9	29.7	30.5
	rel. change of SPP in %					-22.0%	-18.1%	-14.3%	-10.6%	-7.0%	-3.4%	0.0%	3.4%	6.7%	9.9%	13.1%	16.2%	19.2%
Interest rate	abs. change of SPP in a					25.0	25.1	25.2	25.3	25.4	25.5	25.6	25.7	25.8	25.9	26.0	26.1	26.2
	rel. change of SPP in %					-2.2%	-1.9%	-1.5%	-1.1%	-0.7%	-0.4%	0.0%	0.4%	0.8%	1.1%	1.5%	1.9%	2.2%
O&M costs	abs. change of SPP in a	23.2	23.4	23.6	23.9	24.1	24.3	24.6	24.8	25.1	25.3	25.6	25.9	26.1	26.4	26.7	27.0	27.3
	rel. change of SPP in %	-9.5%	-8.6%	-7.7%	-6.8%	-5.9%	-4.9%	-4.0%	-3.0%	-2.0%	-1.0%	0.0%	1.1%	2.1%	3.2%	4.3%	5.4%	6.6%
Utilization rate	abs. change of SPP in a				35.4	33.4	31.8	30.2	28.9	27.7	26.6	25.6	24.7	23.8	23.0	22.3	21.6	
	rel. change of SPP in %				38.3%	30.7%	24.1%	18.2%	13.0%	8.2%	3.9%	0.0%	-3.6%	-6.9%	-10.0%	-12.8%	-15.5%	
Boiler efficiency	abs. change of SPP in a									23.6	24.6	25.6	26.5	27.5				
	rel. change of SPP in %									-7.6%	-3.8%	0.0%	3.7%	7.4%				
System efficiency	abs. change of SPP in a						31.8	30.2	28.9	27.7	26.6	25.6	24.7	23.8	23.0	22.3	21.6	
	rel. change of SPP in %						24.1%	18.2%	13.0%	8.2%	3.9%	0.0%	-3.6%	-6.9%	-10.0%	-12.8%	-15.5%	

Table 36: Results of Sensitivity Analysis of SPP of SHIP Investment using Stationary Collectors; Replaced Fuel: NG; part 1 of 2

Source: own illustration

Change of Input Parameter in %	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%	105%	110%	115%	120%	125%
Annual inflation rate	26.9	27.2	27.5	27.9	28.3	28.7														
	5.2%	6.3%	7.6%	9.0%	10.5%	12.3%														
Natural gas price	21.0	20.4	19.8	19.3	18.8	18.3	17.9	17.5	17.1	16.7	16.3	16.0	15.6	15.3	15.02	14.73	14.44	14.18	13.92	13.67
	-17.9%	-20.3%	-22.5%	-24.5%	-26.5%	-28.3%	-30.0%	-31.7%	-33.3%	-34.8%	-36.2%	-37.5%	-38.9%	-40.1%	-41.3%	-42.4%	-43.6%	-44.6%	-45.6%	-46.6%
Annual energy price increase	21.3	20.7	20.2																	
	-16.9%	-19.0%	-21.0%																	
Specific total investment cost	30.5	31.3	32.0	32.8	33.5	34.2	34.9	35.6	36.3	37.0										
	19.2%	22.2%	25.2%	28.1%	30.9%	33.8%	36.6%	39.3%	42.0%	44.7%										
Interest rate	26.2	26.3	26.3	26.4	26.5															
	2.2%	2.6%	3.0%	3.3%	3.7%															
O&M costs	27.3	27.6	27.9	28.2	28.5	28.8	29.1	29.5	29.8	30.2	30.5	30.9	31.2	31.6	32.0					
	6.6%	7.7%	8.9%	10.1%	11.3%	12.6%	13.9%	15.2%	16.5%	17.9%	19.2%	20.6%	22.1%	23.5%	25.0%					
Utilization rate																				
Boiler efficiency																				
System efficiency																				

Table 37: Results of Sensitivity Analysis of SPP of SHIP Investment using Stationary Collectors; Replaced Fuel: NG; part 2 of 2

Source: own illustration

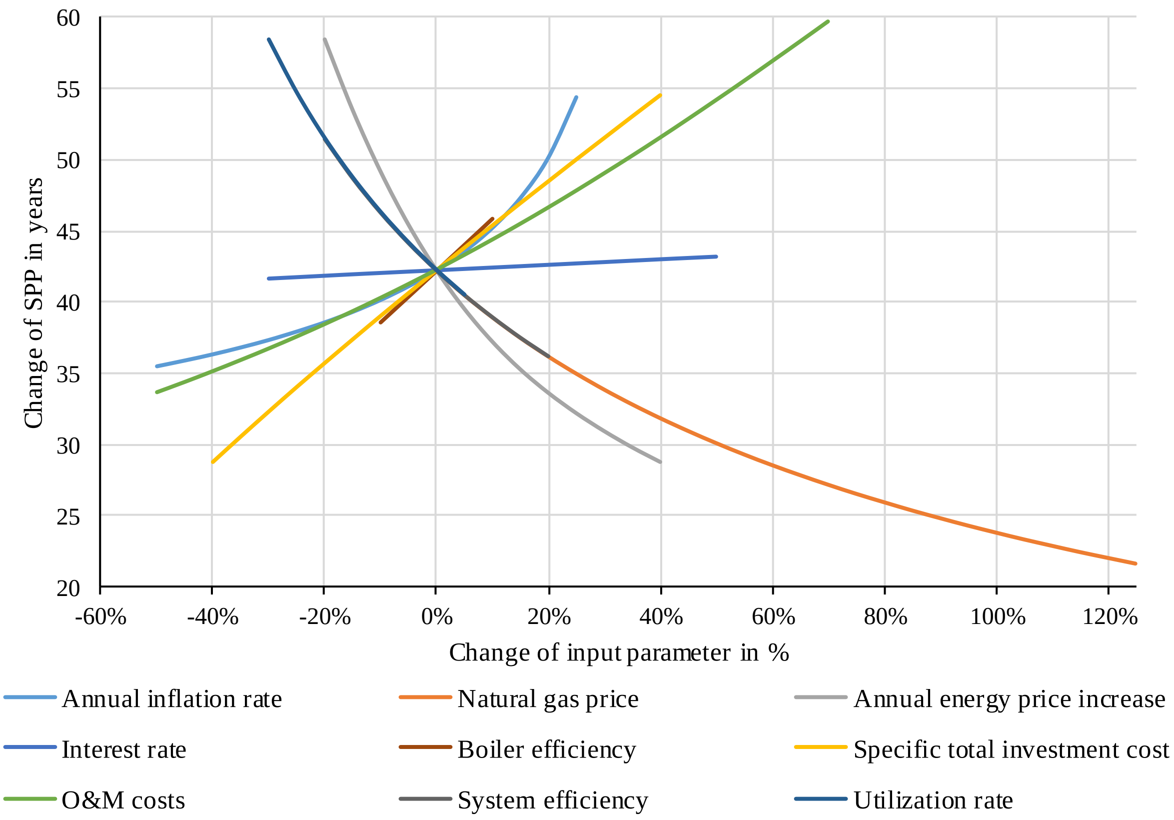

Figure 29: Sensitivity Analysis of SPP of SHIP Investment using Concentrating Collectors; Replaced Fuel: NG

Source: own illustration

M Cash Flows of Best Case SHIP Investment

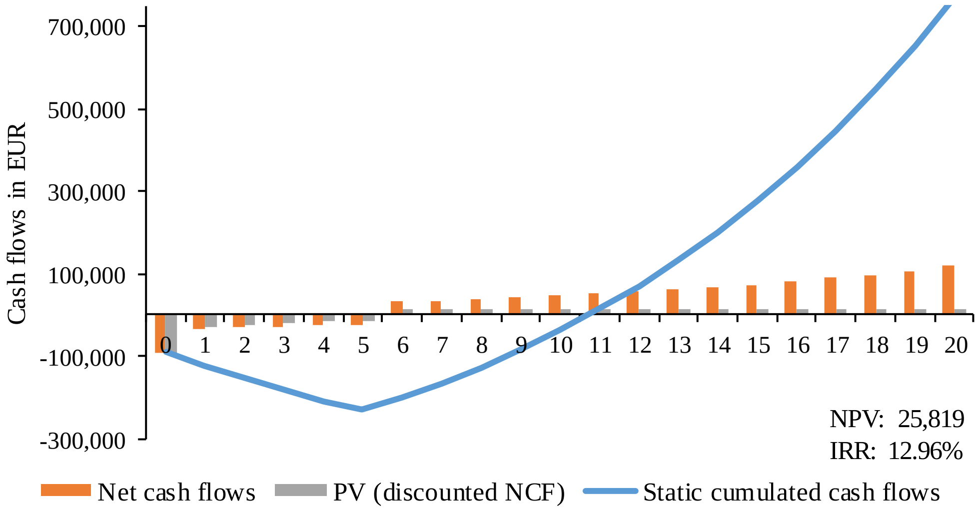

Figure 30: Cash Flows of Best Case SHIP Investment Using Stationary Technologies; Replaced Fuel: NG
Source: own illustration

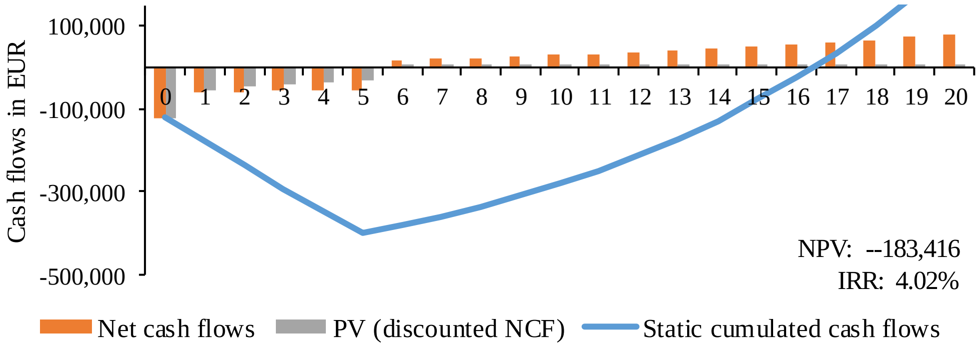

Figure 31: Cash Flows of Best Case SHIP Investment Using Concentrating Technologies; Replaced Fuel: NG
Source: own illustration

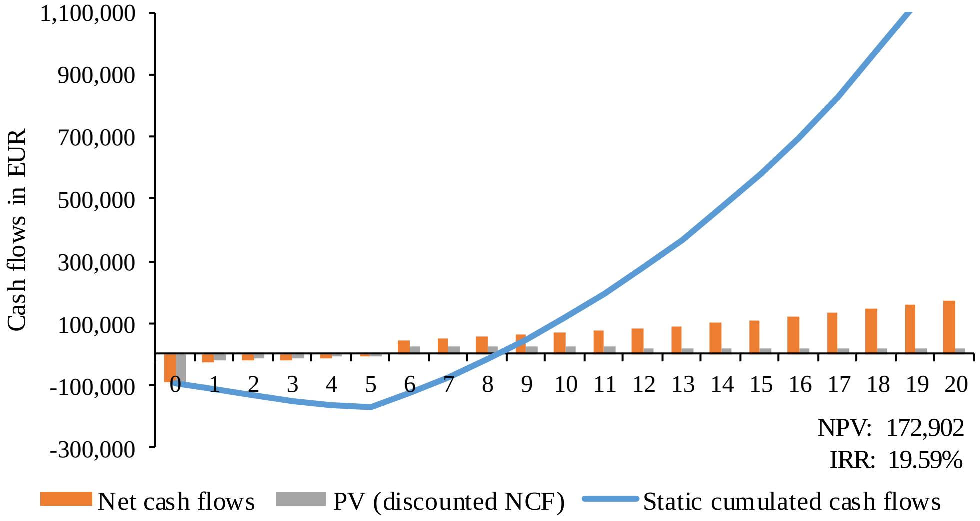

Figure 32: Cash Flows of Best Case SHIP Investment Using Stationary Technologies; Replaced Fuel: FO
Source: own illustration

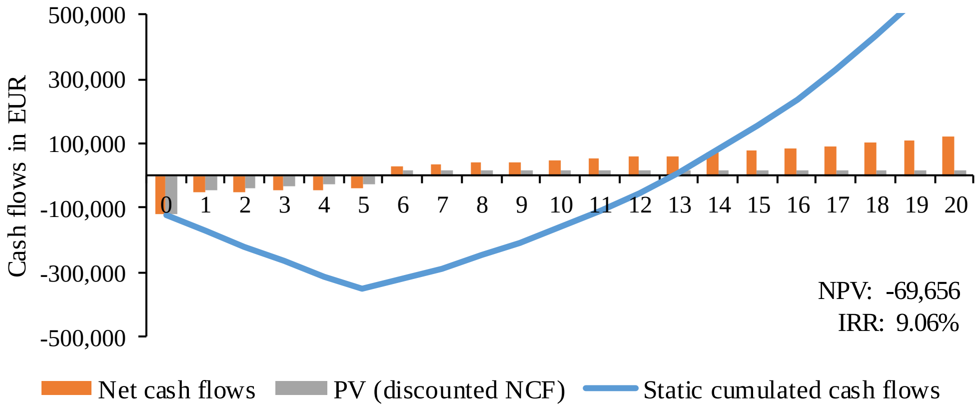

Figure 33: Cash Flows of Best Case SHIP Investment Using Concentrating Technologies; Replaced Fuel: FO

Source: own illustration

N Cash Flows of SHIP Investments with Financial Policy Instruments

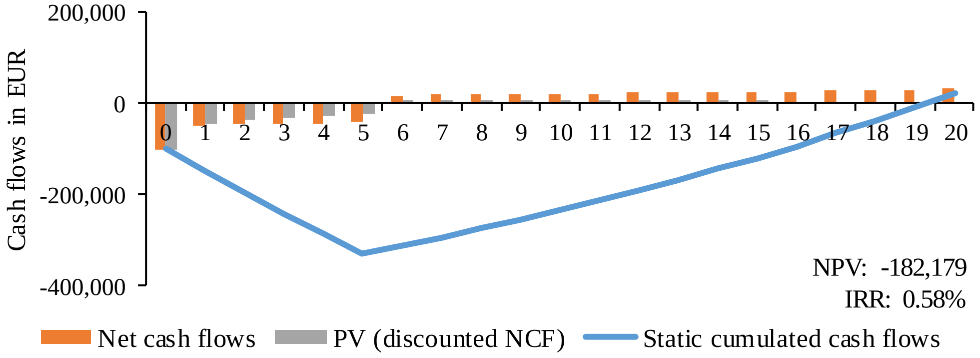

Figure 34: Cash Flows of Reference SHIP investment Using FPC with Current Grant of 16.25%; Replaced Fuel: NG

Source: own illustration

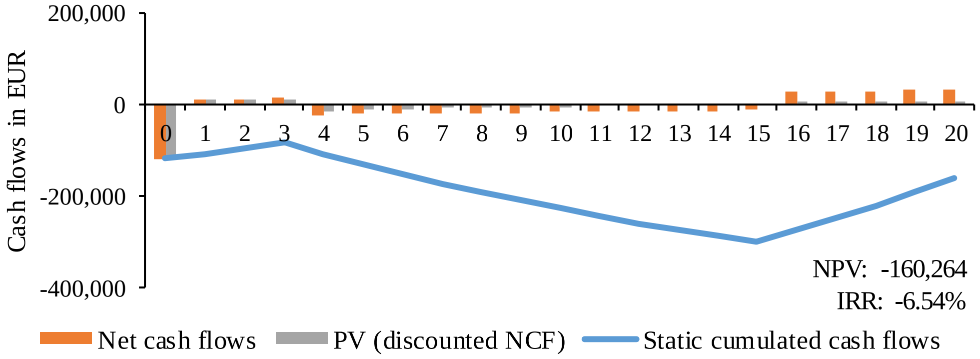

Figure 35: Cash Flows of Reference SHIP Investment Using FPC and Financed with a Soft Loan; Replaced Fuel: NG

Source: own illustration

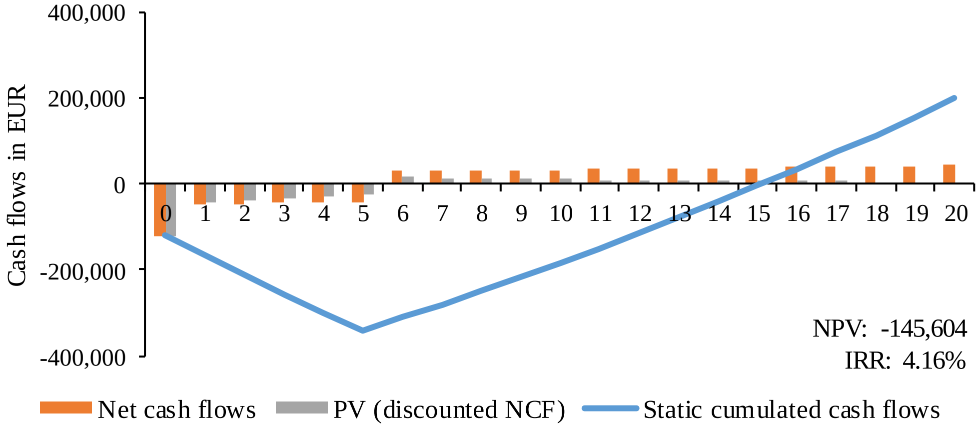

Figure 36: Cash Flows of Reference SHIP Investment Using FPC with a Bonus Payment of 1.5 EUR cents/kWh; Replaced Fuel: NG

Source: own illustration

O Public Costs

t		Mean cost price	Industrial retail price (excl. VAT) reference case	Total subsidies (mean cost-retail price)	Fuel Savings reference FPC, 1000m²	Specific public savings (FPC)	Discounted specific public savings (FPC)	Discounted specific public savings (ETC)	Discounted specific public savings (Conc)
		EUR cents/kWh	EUR cents/kWh	EUR cents/kWh	kWh/1000m²	EUR/m²	EUR/m²	EUR/m131	EUR/m132
	increase in %/a	1%	2015-21: 10% then: 5%						
	2012								
	2013								
0	**2014**	3.10	1.38	1.72					
1	**2015**	3.13	1.52	1.61	880,094	14.20	13.07	11.04	11.01
2	**2016**	3.16	1.67	1.49	875,694	13.07	11.09	9.36	9.33
3	**2017**	3.19	1.84	1.36	871,315	11.83	9.24	7.80	7.78
4	**2018**	3.23	2.02	1.21	866,959	10.45	7.52	6.35	6.33
5	**2019**	3.26	2.22	1.04	862,624	8.93	5.92	5.00	4.98
6	**2020**	3.29	2.44	0.85	858,311	7.26	4.43	3.74	3.73
7	**2021**	3.32	2.57	0.76	854,019	6.46	3.63	3.07	3.06
8	**2022**	3.36	2.70	0.66	849,749	5.62	2.91	2.46	2.45
9	**2023**	3.39	2.83	0.56	845,500	4.74	2.26	1.91	1.90
10	**2024**	3.42	2.97	0.45	841,273	3.81	1.67	1.41	1.41
11	**2025**	3.46	3.12	0.34	837,066	2.83	1.15	0.97	0.96
12	**2026**	3.49	3.28	0.22	832,881	1.81	0.67	0.57	0.57
13	**2027**	3.53	3.44	0.09	828,717	0.73	0.25	0.21	0.21
14	**2028**	3.56	3.61	-0.05	824,573	-0.40	-0.13	-0.11	-0.11
15	**2029**	3.60	3.79	-0.19	820,450	-1.59	-0.46	-0.39	-0.39
16	**2030**	3.63	3.98	-0.35	816,348	-2.83	-0.76	-0.64	-0.64
17	**2031**	3.67	4.18	-0.51	812,266	-4.14	-1.02	-0.86	-0.86
18	**2032**	3.71	4.39	-0.68	808,205	-5.51	-1.25	-1.06	-1.06
19	**2033**	3.75	4.61	-0.86	804,164	-6.95	-1.46	-1.23	-1.23
20	**2034**	3.78	4.84	-1.06	800,143	-8.46	-1.63	-1.38	-1.37
						61.83	**57.10**	**48.21**	**48.07**

Table 38: Calculation of NPV of Specific Public Savings if NG is Replaced
Source: own illustration; assumption based on Table 4, p. 15, Figure 10, p. 17, and Table 5, p. 18

t		**Mean cost price** (3x retail price)	**Industrial retail price (excl. VAT)** reference case	**Total subsidies** (2x retail price)	**Fuel Savings** reference FPC, 1000m²	**Specific public savings** (FPC)	**Discounted specific public savings** (FPC)	**Discounted specific public savings** (ETC)	**Discounted specific public savings** (Conc)
		EUR cents/kWh	EUR cents/kWh	EUR cents/kWh	kWh/1000m²	EUR/m²	EUR/m²	EUR/m131	EUR/m132
	increase in %/a	1%	2015-21: 10% then: 5%						
	2012	6.45	2.15						
	2013	6.51							
0	**2014**	6.58	2.28	4.30					
1	**2015**	6.65	2.51	4.14	880,094	36.41	33.54	28.32	28.23
2	**2016**	6.71	2.76	3.95	875,694	34.62	29.36	24.79	24.72
3	**2017**	6.78	3.03	3.74	871,315	32.62	25.49	21.52	21.46
4	**2018**	6.85	3.34	3.51	866,959	30.42	21.88	18.48	18.43
5	**2019**	6.92	3.67	3.24	862,624	27.98	18.54	15.65	15.61
6	**2020**	6.98	4.04	2.95	858,311	25.28	15.43	13.03	12.99
7	**2021**	7.05	4.24	2.81	854,019	24.02	13.50	11.40	11.37
8	**2022**	7.12	4.45	2.67	849,749	22.70	11.75	9.92	9.89
9	**2023**	7.20	4.68	2.52	845,500	21.31	10.16	8.58	8.55
10	**2024**	7.27	4.91	2.36	841,273	19.84	8.71	7.36	7.33
11	**2025**	7.34	5.16	2.19	837,066	18.29	7.40	6.25	6.23
12	**2026**	7.41	5.41	2.00	832,881	16.67	6.21	5.24	5.23
13	**2027**	7.49	5.68	1.80	828,717	14.96	5.13	4.33	4.32
14	**2028**	7.56	5.97	1.60	824,573	13.16	4.16	3.51	3.50
15	**2029**	7.64	6.27	1.37	820,450	11.26	3.28	2.77	2.76
16	**2030**	7.72	6.58	1.14	816,348	9.27	2.48	2.10	2.09
17	**2031**	7.79	6.91	0.88	812,266	7.18	1.77	1.50	1.49
18	**2032**	7.87	7.25	0.62	808,205	4.98	1.13	0.96	0.95
19	**2033**	7.95	7.62	0.33	804,164	2.67	0.56	0.47	0.47
20	**2034**	8.03	8.00	0.03	800,143	0.25	0.05	0.04	0.04
						373.90	**220.52**	**186.21**	**185.66**

Table 39: Calculation of NPV of Specific Public Savings if FO is Replaced
Source: own illustration; assumption based on Table 4, p. 15, Table 27, p. 59, and Table 5, p. 18

t		Mean cost price	Industrial retail price (excl. VAT) reference case	Total subsidies (mean cost-retail price)	Fuel Savings reference FPC, 1000m²	Specific public savings (FPC)	Bonus payment	Specific public costs (FPC)	Specific net public costs (FPC)	Discounted net specifc public costs (FPC, d_{nom}=8.58%)
		EUR cents/kWh	EUR cents/kWh	EUR cents/kWh	kWh/1000m²	EUR/m²	EUR cents/kWh	EUR/m²	EUR/m²	EUR/m²
	increase in %/a	1%	2015-21: 10% then: 5%							
	2012									
	2013									
0	**2014**	3.10	1.38	1.72						
1	**2015**	3.13	1.52	1.61	880,094	14.20	1.50	13.20	-0.99	-0.92
2	**2016**	3.16	1.67	1.49	875,694	13.07	1.50	13.14	0.07	0.06
3	**2017**	3.19	1.84	1.36	871,315	11.83	1.50	13.07	1.24	0.97
4	**2018**	3.23	2.02	1.21	866,959	10.45	1.50	13.00	2.55	1.84
5	**2019**	3.26	2.22	1.04	862,624	8.93	1.50	12.94	4.01	2.65
6	**2020**	3.29	2.44	0.85	858,311	7.26	1.50	12.87	5.61	3.43
7	**2021**	3.32	2.57	0.76	854,019	6.46	1.50	12.81	6.35	3.57
8	**2022**	3.36	2.70	0.66	849,749	5.62	1.50	12.75	7.13	3.69
9	**2023**	3.39	2.83	0.56	845,500	4.74	1.50	12.68	7.95	3.79
10	**2024**	3.42	2.97	0.45	841,273	3.81	1.50	12.62	8.81	3.87
11	**2025**	3.46	3.12	0.34	837,066	2.83	1.50	12.56	9.72	3.93
12	**2026**	3.49	3.28	0.22	832,881	1.81	1.50	12.49	10.69	3.98
13	**2027**	3.53	3.44	0.09	828,717	0.73	1.50	12.43	11.70	4.01
14	**2028**	3.56	3.61	-0.05	824,573	-0.40	1.50	12.37	12.77	4.03
15	**2029**	3.60	3.79	-0.19	820,450	-1.59	1.50	12.31	13.90	4.04
16	**2030**	3.63	3.98	-0.35	816,348	-2.83	1.50	12.25	15.08	4.04
17	**2031**	3.67	4.18	-0.51	812,266	-4.14	1.50	12.18	16.33	4.03
18	**2032**	3.71	4.39	-0.68	808,205	-5.51	1.50	12.12	17.64	4.01
19	**2033**	3.75	4.61	-0.86	804,164	-6.95	1.50	12.06	19.02	3.98
20	**2034**	3.78	4.84	-1.06	800,143	-8.46	1.50	12.00	20.47	3.95
						61.83		**251.86**	**190.02**	**62.94**

Table 40: Calculation of Discounted Net Specific Public Costs if NG is Replaced
Source: own illustration; assumption based on Table 4, p. 15, Figure 10, p. 17, and Table 5, p. 18

P Expert Interviews

Interview with Salvatore Moretta, co-author of Calderoni et al. (2012) and as a MEDREC-employee jointly responsible for the realization of the first SHIP pilot plant in Tunisia, 10.06.2014

- What were the specific investment costs for the Benetton plant?
  About 800 TND/m², but this includes only material costs. Planning and Design is not considered and was done by Politecnico Milano.
- Which solar heat integration is easier?
  It is easier to feed in process heat on the steam-side (supply level). Water-side is difficult and leads to high material costs for integration. Further, planning phase takes long. 2 years in the case of the Benetton plant. Standardized integration concepts for certain sectors like dairies are necessary. There is the trade-off between low temperature, which leads to more complex solar integration on water-side, and medium temperature, which increases collector costs but facilitates integration on steam-side.

Interview with Ali Ben Hmid, Tunisian energy expert and consultant. 04.08.2014

- Which industries use high pressure natural gas?
  Those are few. Basically power plants and some heavy industries.
- Which electricity tariff is paid by industries?
  High voltage only applies for very few industries. The majority obtains medium voltage. The uniform price is still listed, but usually not granted for industries. Almost all pay the tariff depending on time of day.
- Are the electricity prices linked to NG prices?
  Yes, in the past, price have been increased for NG and electricity together
- Do industries have to pay VAT on energy prices or is it deducted?
  For energy there is no pre-tax deduction, as there is for other raw products.
- What conditions (interest rate, repayment period, grace period) can be expected for a loan of a private bank to finance a SHIP investment?
  It depends a lot on the individual relation between the bank and the industrialist. If it is a good industrialist with a strong connection to a bank, an interest rate of TMM+3 is can be assumed. Repayment is usually around five, but not more than seven years. Grace periods are not usual.

Interview with Afef Chachi Tayari, vice director of National Observatory of Energy, 13.07.2014

- Where do indirect energy subsidies for come from?
  The ETAP buys NG and crude oil from the Algerian export company Sonatrach at the international price. NG is then sold to the STEG at a price of 90.8 TND/toe. This price is set by the ministry of industry. The import price for Algerian gas is about ten times as high. The difference is paid by the ETAP which usually generates profits with oil exploration. This can be seen as a major indirect subsidy.

Telephone interview with Wolfgang Glatz, AEE INTEC, 19.08.2014

- Göss Brewery: Which costs are included in „material heat integration“?
  Costs for integration of distance heating (incl. heat exchanger) and reconstruction of mashing container
- Are costs of integration on process level generally higher than on supply level?
  No, that is difficult to generalize.
- Are there economies of scale effects for larger plants?
  Yes, they can be seen, but very little, because system costs still vary widely. System costs of realized project often do not reflect the costs expected in a competitive market. Pilot plants are built in cooperation with research institutes and systems costs are not as important, as it is seen as research project. Therefore, it is important to consider the organizational context of each project.

Q Mail Conversations

Mail Conversation with Stefan Minder, CEO NEP SOLAR; 17.08.2014

Guten Tag Herr Schaffitzel,
Der Skaleneffekt ist gross im Bereich bis 1000m2 und immer noch signifikant im Bereich bis 2000m2. Die Investitionskosten realisierter SHIP Anlagen der AEE Intec Datenbank umfassen die verschiedensten Anlagen mit unterschiedlichsten Kosteneffekten und eignen sich nicht zur Bildung von Trends und Statistiken (meine ich). Der Markt ist noch zu jung um einen solche statistischen Schlussfolgerungen machen zu können.
Zu ihrer Frage bez. Speicher:
- In der Anlage in Saignelégier, Jura speisen wir die Wärme in einen bestehenden 15m3 Speicher.
- Bei den beiden anderen Anlagen (LESA in Bever und Cremo in Fribourg) gibt es keinen Pufferspeicher. Bei Lesa wirkt das Dampfnetz als Puffer und bei Cremo ist der solare Anteil so klein, dass die Wärme jederzeit abgenommen werden kann.
Freundliche Grüsse
Stefan Minder

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-----Original Message-----
From: Filip Schaffitzel [mailto:filip.schaffitzel@tu-dresden.de]
Sent: Samstag, 16. August 2014 23:48
To: stefan.minder@nep-solar.com
Subject: Fragen zu SHIP für Bachelorarbeit

Guten Tag Herr Minder,

ich schreibe zurzeit meine Bachelorarbeit über die Wirtschaftlichkeit von SHIP in Tunesien und habe mich über ihre Vortragsunterlagen
(http://www.aee-intec-events.org/gs2014/images/stories/Vortrge/Vortraege_2014/Minder.pdf)
gefreut, da diese Aufschluss über die Investitionskosten und die Amortisationszeit der beiden PTC-Anlagen gibt. Auch ist die Aufschlüsselung der Kosten interessant, doch hierzu hätte ich eine Frage:
Es sind kein Speicher aufgeführt, ist dieser im zweiten Block enthalten?

Außerdem wird in der Literatur oft davon ausgegangen, dass die spezifischen Systemkosten mit steigender Aperturfläche/Anlagengröße abnehmen. Dies klingt theoretisch auch erst einmal einleuchtend, da flächen-unabhängige Kosten, wie Steuerung oder Planung über die größere werdende Fläche verteilt werden. Außerdem werden Mengenrabatte von Kollektorhersteller gewährt.
Doch die Investitionskosten realisierter SHIP-Anlagen (verfügbar durch die Datenbank von AEE INTEC) spiegeln dies nicht wieder. Ist es womöglich noch zu früh, da in der Pilotphase solche Effekte noch nicht auftreten oder ist dieser Effekt ohnehin für SHIP-Anlagen eher gering, da die spezifischen Investitionskosten noch von vielerlei andere Faktoren, wie Integrationsweise (z.B. Gebrauch von Speicher oder Wärmetauscher, Einspeisung auf Prozess- oder Versorgungsebene) oder Standort abhängen?

Vielen Dank für Ihre Unterstützung und viele Grüße aus Tunis, Filip Schaffitzel

2. Mail conversation with Marco Calderoni, co-author of Frein et al. (2014) and Calderoni et al. (2012); 22.08.2014

Hi Filip,

the plant is being installed now, after a long bureaucratic process.
Collectors are from an Italian company manufacturing in Tunisia. They are selective FPC. Company website is http://www.energiedelsole.com.

Best regards,

Marco

Il 22/08/2014 19:46, Filip Schaffitzel ha scritto:
Hi Marco,

Soon I have to turn in my bachelor thesis, but there is still some work to do. I have three question regarding the collector type used in your publication "Solar thermal plant integration into an industrial process".

- Did you install the same collectors with which you simulated the plant?
- Are they selective FPC?
- Were they manufactured in Tunisia?

I tried to contact Salvatore, but I couldn't get a hold of him. It would be great, if you could help me out.
Thank you and have a nice weekend,

Filip

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Hiermit erkläre ich eidesstattlich, dass ich die vorliegende Arbeit selbständig und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt, sowie die aus fremden Quellen direkt oder indirekt übernommenen Gedanken als solche kenntlich gemacht habe.

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Tunis, den 31.08.2014 Filip Schaffitzel