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Project acronym **MEDISCO**

Project title **MEDiterranean food and agro Industry applications of Solar COoling technologies**

Instrument **Specific Targeted Project**

Thematic Priority **INCO**

D1.2 Report on the Potential energy savings linked to the application of solar cooling technologies in the Mediterranean food and agro industries

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Egyptian Environmental Affairs Agency (EEAA)

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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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PHYSICAL UNITS AND CONVERSION FACTORS

bbl	barrel	(1t = 7.3 bbl)
cal	calorie	(1 cal = 4.1868 J)
Gcal	Giga calorie	
GWh	Gigawatt-hour	
h	hour	
km	kilometer	
km²	square kilometer	
kW	kilo Watt	
kWh	kilo Watt hour	(1 kWh=3.6 MJ)
MBtu	Million British Thermal Units	(= 1 055 MJ = 252 kCal)
	one cubic foot of natural gas produces approximately 1,000 BTU	
MJ	Million Joule	(= 0,948.10^{-3} MBtu = 238.8 kcal)
MW	Mega Watt	
m	meter	
m^3/d	cubic meter per day	
mm	millimeter	
mm^3	million cubic meter	
t	ton	
toe	tons of oil equivalent	
tcf	ton cubic feet	
°C	Degrees Celsius	

General Conversion Factors for Energy

To:	TJ	Gcal	Mtoe	MBtu	GWh
From:	multiply by:				
TJ	1	238.8	2.388 x 10^{-5}	947.8	0.2778
Gcal	4.1868 x 10^{-3}	1	10^{-7}	3.968	1.163 x 10^{-3}
Mtoe	4.1868 x 10^{4}	10^{7}	1	3.968 x 10^{7}	11630
MBtu	1.0551 x 10^{-3}	0.252	2.52 x 10^{-8}	1	2.931 x 10^{-4}
GWh	3.6	860	8.6 x 10^{-5}	3412	1

Introduction

The European project MEDISCO, part of the 6th Framework Programme, seeks to develop, test and optimise solar-cooling concepts for the agro-food industry in the Mediterranean Basin, concepts which, considering local conditions, might prove economically and socially sustainable.

After having analysed the Agro-Food Industry (AFI) and determined the penetration potential of solar cooling in this sector, this project seeks to define which technologies might best suit current and future requirements in the food and preservation sectors on the Mediterranean Basin's south bank. The selected technologies will be implemented at two pilot sites, which will be monitored to study their performance and verify their functionality. In other words, the scope of the project is to determine which methodology is technically and economically best suited to install high-performance solar-cooling systems meant as the best compromise between innovative technologies, primary-energy savings and cost-effectiveness.

This deliverable designated "D1.2 will identify what are the potential energy savings obtained through the introduction of the solar cooling technologies. This deliverable addresses policies mechanisms and financial schemes able to ease, under local conditions, the adoption of high energy efficient technologies and systems.

Under different scenarios, the evaluation of the potentials was forecasted and performed, with regard to : primary energy savings, power demand reduction, environmental and social benefits. The results will constitute the background for the implementation of future research and development activities and projects related to solar cooling applications in the post harvest, storage, processing of agricultural products and food on industrial sectors, in the three countries.

This document is structured in three volumes:

- Profile and projections of FAI in the three countries involved; including forecast of electricity consumption for all industries , forecast of electricity FAI consumption, forecast of cooling electricity consumption for FAI and forecast of primary energy saving achieved by the implementation of solar cooling IN FAI.
- Fuel price projection as it directly impact the profitability of the solar cooling systems
- Review of the specific legislation, policy mechanisms, and financial schemes able to ease solar cooling penetration
- Summary of the results of the three studies of the agro-food industry in Tunisia, Morocco and Egypt;

Volume 1: Executive summary of D1.1

1.1. Description of the Industry

Table 1. General description of dairy, beverage, frozen vegetables and meat

Dairy	Beverage	Frozen Vegetables	Meat
Characterized by the multitude of products and therefore production lines. Plants can have as few as one or two production lines or all of them. Service and ancillary units provide water and energy requirements as well as maintenance, storage, packaging, testing and analysis needs. Because of the nature of milk and milk products, which are susceptible to microbial spoilage, equipment is characterized by designs which facilitate hygienic operation, easy cleaning and sterilization. While many older plants use open equipment and batch processing, modern dairy food plants used closed systems operated continuously for periods up to 24 hours. Shut down for cleaning is generally required at least per day.	The carbonated beverages industry has been identified as a contributor to the pollution of waterways especially when large industrial establishments are involved. Major processes at this industry are automated and operated in the continuous mode. The production is subject to seasonal variation as production drops in winter. Wastewater is generated mainly from bottle washing and spills during filling operations as well as rejects. The production is subject to seasonal variation as production drops in winter.	Vegetables are received in containers. They are visually tested for quality. If accepted they are dumped into a washing basins, where air /steam is introduced to improve washing and mixing. Vegetables are transported by belt conveyors to a secondary wash zone that uses sprays of clean water for a final wash. The vegetables are peeled, trimmed and cut depending on the type of vegetable. This step generates a large amount of solid waste. The prepared vegetable are partially cooked in a jacketed vessel where steam is introduced in the jacket to provide heat. Some facilities use live steam injected directly in the vessel.	Meat and poultry livestock are visually tested for quality. If accepted they are slaughtered and dumped into washing basins where air is introduced to improve washing. Red and white meat are transported by vertical conveyors to a secondary wash zone that uses sprays of clean water for a final wash. The slaughtered livestock are peeled, cutting, mincing grinding, seasoning and formatted.

1.2. Raw Materials, Products and Utilities

Table 2. Raw Materials, Products and Utilities of dairy, beverage, frozen vegetables and meat industries

Dairy	Beverage	Frozen Vegetables	Meat
Fresh cow and buffalo milk, powder milk, rennet, Roquefort fungi (for Roquefort cheese), yeast, butter oil, starter for yogurt, preservatives, green pepper. Chemicals are used in the lab for quality control and analysis. Detergents and antiseptics are used for cleaning and sterilization purposes (sodium hydroxide, nitric acid, sodium hypochlorite). Steam is generated in boilers that use either mazot (fuel oil), solar (gas oil) or natural gas as fuel. Steam is used for providing heat requirements . Pasteurization takes place in a plate-type heat exchanger by successive heating to 100C then sudden cooling using cooling water.	Water, carbon dioxide and concentrates are the main raw materials used in this industry. Additives such as fructose, sucrose and flavors, are also used. Chemicals such as sodium chloride, ferrous sulfate, calcium hypochlorite, lime, potassium permanganate and sodium hydroxide are used for water treatment. Mono ethanol-amine and sodium carbonate are used in the carbon dioxide production process for purifying the gas. Chemicals are also used in the lab for quality control and analysis. Detergents and antiseptics are used for cleaning and sterilization purposes.	Cold water (5-6º C) is passed over the half cooked vegetables and then introduced on a belt conveyor into a tunnel freezer where quench cooling occurs at a temperature less than –20ºC. This process takes 20 minutes and preserve the vegetables. Only the outer surface of the vegetables freezes without affecting its properties. Frozen vegetables are packed manually in pouches and stored in freezers. Cooling water is used for the compressors of the freezers. Freon (commercial name for CFCs) and ammonia are usually used as a refrigerant. Frozen vegetables are packaged and stored at about (-18C) in freezers.	Cow, buffalo, Camel, mouton and chicken. Steam is generated in boilers that use either mazot (fuel oil), solar (gas oil) or natural gas as fuel. Boilers are used to produce steam for heat supply to the heating processes and as heat supply to the cooling and refrigeration processes

1.3. Electrical energy situation in Tunisia, Morocco and Egypt

Table 3. Synoptic table of the Electrical energy situation in Tunisia, Morocco and Egypt in 2006

		TUNISIA	MOROCCO	EGYPT
Electricity Demand	**Energy Demand**			
	Total energy consumption (Mtoe)	5.713	13.1	34.99
	Electricity consumption (Mtoe)	1.010	1.82	7.8
	Electricity consumption (GWh)	10.868	21105	90290
	Peak load (GW)	2.450	5.283	17.3
	Consumption per sector (GWh)			
	Agriculture	760.76(7%)	1310 (6.38 %)	3611.6 (4.00 %)
	Industry	3912.48(36%)	14466.23 (70.43 %)	32053 (35.50 %)
	Residential	1847.56(17%)	2905 (14.15 %)	33136.4 (36.70 %)
	Others	4347.2 (40%)	1857.90 (9.04%)	21489 (23.8 %)
	Total	10868	21105	90290
	Annual Energy Demand Evolution (GWh)			
	2002	9102	14141	69181
	2003	9586	15214	74990
	2004	10068	21105	80565
	2005	10491	19518	86091
	2006	10868	21104.6	90290

1.4. General summary of cold in the FAI industries in Tunisia, Morocco and Egypt

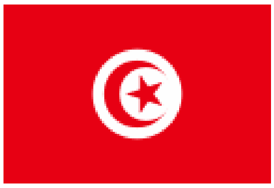
Table 4. Synoptic table of the three studies carried out in Tunisia, Morocco and Egypt

			TUNISIA	MOROCCO	EGYPT
Cold in the FAI	General summary of cold in the sector	**cold-storage capacities**	volume: 1 310 011 m^3	volume: 1 700 000 m^3	volume: 3 025 596 m^3
		Refrigerating capacity	- storage capacities are insufficient, except for seafood	- 370 000 tonnes refrigeration (TR), equal to , 1 301 MW power installed	- 648 342 tonnes refrigeration (TR), equal to , 2 276 MW power installed - 116 300 TR equal to 409 MW power installed for cold-storage containers located at the main ports
		Industry size	-945 companies with over 10 employees -60,000 employees - “Fruits and vegetables” and “seafood” activities represent nearly 84% of installed storage capacity.	- 2,016 companies (24% of industrial companies), 66% are used in “Fruits and vegetables” - 95% of them are SME - 110,000 employees - one of the main sectors of the country’s economy, but exports only 17% of production (quality and health issues)	- 3932 production units : 215 frozen vegetables , 3334 milk and derivatives, 158 beverage and 225 meat, poultry and fish”, with 440,000 total number of employees.

VOLUME 2: FAI FORECAST STUDIES IN TUNISIA, M OROCOO AND EGYPT

1. STRATEGIC STUDY OF TUNISIA

1. Strategic study of Tunisia



The study was conducted by the Agence Nationale pour la Maitrise de l'Energie (ANME) .

To conduct the study as per the proposed methodology, the ANME used the official documents and strategic studies on the AFI:

- Ministry of Industry, Energy and SME's
- Agro-food technologies centre
- The industry's promotional agency

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<u>Introduction: strategic overview</u>

Until the middle of the Eighties, Tunisia has enjoyed a favourable energy situation characterized by a largely surplus energy balance. Thus, the energy sector played during this period a key role in financing the economic growth of the country, representing in 1980 approximately 13% of the national GDP and 16% of the national exports.

However, since the end of the Eighties, this favourable situation started to deteriorate under the join effect of two major factors:

-The stagnation of the national hydrocarbon resources;

-The rapid increase of energy demand, as induced by economic and social growth.

Thus, the energy balance moved from a surplus situation of approximately 3 Mtoe in the beginning of the Eighties to a slightly deficit situation starting early year 2000. The contribution of the energy sector in the economic growth has been decreasing since 1986.

Currently, the energy sector accounts for approximately 5% of the GDP of the country and less than 7% of the total national exports.

2.1.1. Steps Taken to Produce the Forecast

2.1.1.1. Analyses of Historical Data

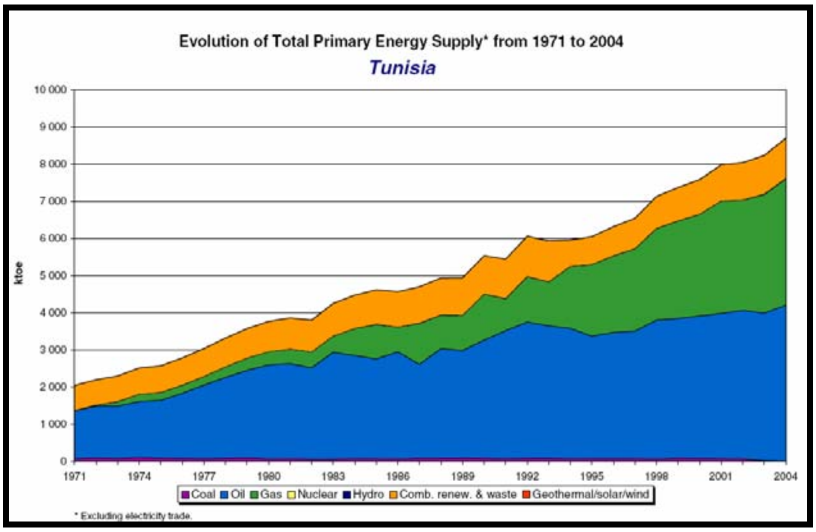


Fig.1. Evolution of Total Primary Supply from 1971 to 2004 in Tunisia

National resources of primary energy (including natural gas royalties perceived from the trans-Mediterranean gas pipeline) reached the equivalent of 7, 6 millions TEP compared to 6, 5 millions TEP the previous year.

This increase of about 17 % in national energy resources is basically due to the substantial increase of crude oil production of about 40 %. However, national resources in natural gas recorded in 2007 a decline of about 190 thousand TEP with regard to 2006 resulting from the double decrease of the national production and the royalty perceived from the trans-Mediterranean gas pipeline.

Tunisia is increasingly turning to natural gas to meet domestic energy demand. The state-owned natural gas and electricity company, Société Tunisienne de l'Electricité et du Gaz (STEG) has promoted the use of natural gas through an incentive system that began in 2005. According to STEG, natural gas represented 44 percent of the total initial energy consumption in Tunisia in 2005, compared to just 14 percent in 2003. Source OGJ

National production of electric power injected into the grid system (STEG, IPP and purchases near the own producers) amounted to 13 146 GWh in 2007 against 12 547 GWh in 2006 recording an increase in 4,8% compared to 2006.

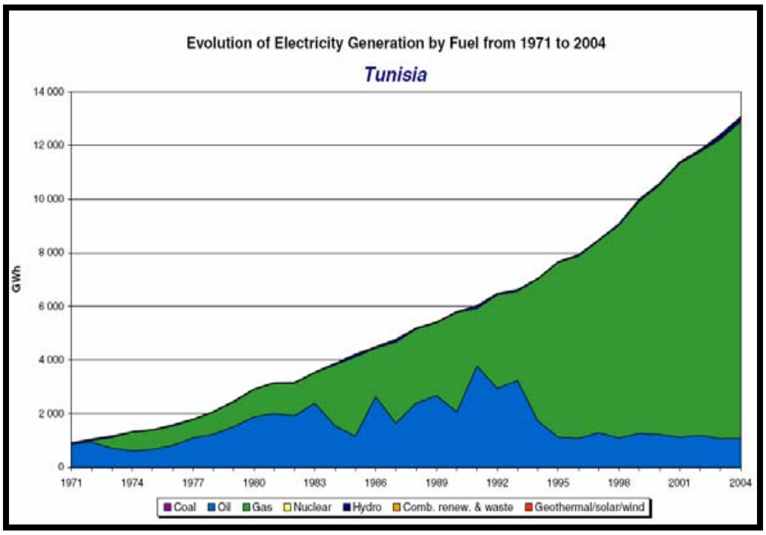


Fig.2. Evolution of Electricity Generation by Fuel from 1971 to 2004 in Tunisia

National production of electric power injected into the grid system (STEG, IPP and purchases near the own producers) amounted to 13 146 GWh in 2007 against 12 547 GWh in 2006 recording an increase in 4,8% compared to 2006.

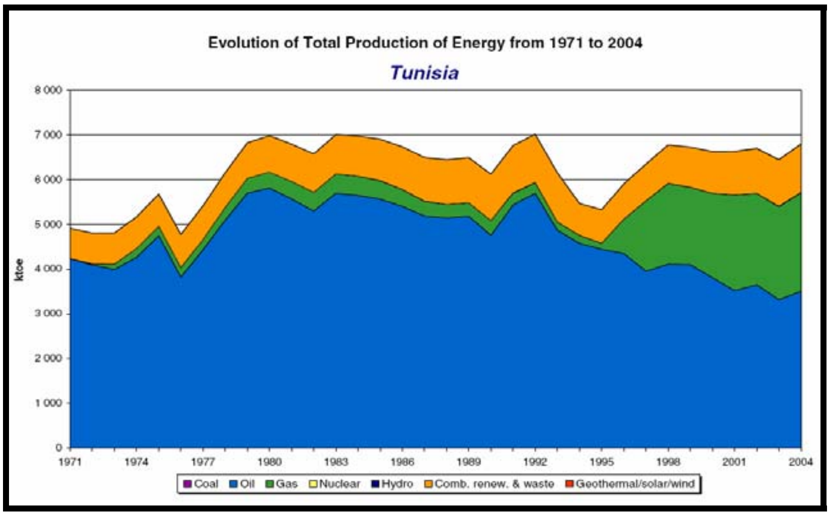


Fig.3. Evolution of Total Production of Energy from 1971 to 2004 in Tunisia

National oil production is currently around 95,000 bbl/d. 76% of the total oil is produced from six main concessions . National sales gas production in 2007 about 6 MNm3/d. It comes mainly from Miskar gas field (southern offshore Tunisia : 4.5 MNm^3/d.

Concerning the gas, the consumption reached **3.617 KTeo** and the number of customers passed, end 2005, from **25.000** into **238.500**.

	2007	2006
GAS Availability	**4.300 KTeo**	**4.138 KTeo**
Gas Customers		
High pressure **Medium pressure** **Low pressure**	**18** **1.140** **332.967**	**17** **1.017** **282.758**
Source: STEG, Annual activities report 2007		

VOLUME 2: FAI FORECAST STUDY IN TUNISIA

The study was conducted by the Agence Nationale pour la Maitrise de l'Energie (ANME) from 01 June 2006 on. The report was submitted on 15 November 2008. The Egyptian Environmental Affairs Authority is the steering agency for the studies.

To conduct the study as per the proposed methodology, the ANME used the official documents and strategic studies on the AFI:

- Ministry of Industry, Energy and SME's
- Agro-food technologies centre
- The industry's promotional agency

The study did not cover certain issues in the methodology. Furthermore, the study failed to proceed with the forecast of electricity and oil consumption for industries for the period 2008- 2030 and no analysis were provided .

Introduction: strategic overview

Until the middle of the Eighties, Tunisia has enjoyed a favourable energy situation characterized by a largely surplus energy balance. Thus, the energy sector played during this period a key role in financing the economic growth of the country, representing in 1980 approximately 13% of the national GDP and 16% of the national exports.

However, since the end of the Eighties, this favourable situation started to deteriorate under the join effect of two major factors:
-The stagnation of the national hydrocarbon resources;
-The rapid increase of energy demand, as induced by economic and social growth.

Thus, the energy balance moved from a surplus situation of approximately 3 Mtoe in the beginning of the Eighties to a slightly deficit situation starting early year 2000. The contribution of the energy sector in the economic growth has been decreasing since 1986.
Currently, the energy sector accounts for approximately 5% of the GDP of the country and less than 7% of the total national exports.

VOLUME 2: FAI FORECAST STUDY IN TUNISIA

2.1.1.3. Forecast of evolution of electricity and natural gas consumption of industry

The forecast of the evolution of electricity and natural gas consumption of industry during the period from 2009 to 2030 is estimated from the national evolution of electricity and natural gas consumption and according to the share of the industry in the electricity and natural gas consumption.

The total industry prime energy consumption was varying during the period from 2009 to 2030 according to high, medium and low scenarios.

2.1.1.4. Forecast of electricity consumption for food and agro industries

The evolution of electricity consumption of food industries from 2009 to 2030 is forecast on the table related to the *“Electricity consumption for cooling purposes on Food and Agro Industries”*.

Tree scenarios indicate the food industries electricity consumption from 2009 to 2030

According to the low scenario primary energy consumption increase from 505 Kteo of electricity on 2008 to 840 Kteo on 2030.

According to the high scenario primary energy consumption increase from 505 Kteo of electricity on 2008 to 890 Kteo on 2030.

2.1.1.5. Forecast of cooling electricity consumption for Food and Agro Industries

.The evolution of cooling production of food industries from 2009 to 2030 is forecast on the table related to the *“Electricity consumption for cooling purposes on Food and Agro Industries”*.

Tree scenarios indicate the food industries consumption from 2009 to 2030.

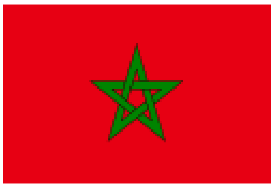
The high scenarios indicate that the cooling production will consume on 2008: 208 Gwh increased on 2030 to 273 Gwh.

The low scenarios indicate that the cooling production will consume on 2008: 208 Gwh increased on 2030 to 256 Gwh.

2.1.1.6. Forecast of primary energy saving achieved by the implementation of solar cooling

The primary energy saved by implementing the solar energy for cooling purpose on Food and Agro Industries according to the low, medium and high scenarios are developed according to a yearly integration of the cooling plant, the electricity saved on 2030 is 0.148 Gwh, 46.54 Gwh according to the low and high scenarios respectively

2.2. Strategic study of Morocco



The study was conducted by the Renewable Energy Development Center (CDER) .

To conduct the study as per the proposed methodology, the CDER called upon professional establishments:

- Professional association of the Cold sector
- National Statistics Directorate
- Ministry of Industry and Trade
- Ministry of Energy

The study covered most of the methodology's issues. The country's general description and the classification of its energy dependence were prepared in the course of writing, using a source the two other studies had in common.
The results of the questionnaire completed by the companies were the subject of a synthetic return per company. As part of the study summary, the document confronted the results by theme to follow the methodology.

<u>Introduction: strategic overview</u>

The general introduction to Morocco revealed its energy stakes. First of all, population growth and, particularly, changing lifestyles have led to significant increases in energy demand. Moreover, Morocco produces no fossil fuel. Despite resorting to renewable energies (the country's main energy resources), Morocco must still import a significant amount of crude oil. Thus, Morocco is highly dependent on exporting countries. Electricity production is rising fast, but a considerable part (70%) is produced by thermal power stations (coal and fuel). Morocco recognises the importance of renewable energy sources, and fosters their use.

The AFI is one of the main sectors of the Moroccan economy. The sector is showing strong growth. However, exports are still relatively low because of difficulties in complying with the quality and sanitary criteria of customer countries. Morocco has launched a policy that provides incentives for AFI investment, both to promote exports and to rationalise energy consumption. These measures mainly involve cold, an essential element of this sector. However, the country's storage capacities are low and must be developed, despite their being energy intensive.

The study on companies' cold requirements revealed that the fish, dairy and storage industries are the AFI's main activities in terms of number of companies and power used for cold production.

2.2.1. Steps Taken to Produce the Forecast

2.2.1.1 Analyses of Historical Data

Morocco only produces 5.5% of the energy it consumes. Oil products account for two thirds of Morocco's energy consumption. Most of the country's energy needs are met through imports. The Domestic energy resources are limited, which explains the strong dependency on energy imports exceeding 96 %. Morocco's annual consumption is 13.1 million TOE, of which 21.105 GWh is electric. The total consumption of energy was increased from 4.6 Mtoe in 1980 to 13.1 Mtoe in 2006 where the consumption of electricity was jumping from 4 460 GWH in 1980 to 21 104 GWH in 2006 and the Energy bill has soared from 4.5 billion US$ in 2005 to 5.75 billion US$ in 2006. As shown in the following table the energy consumption per habitant was increased from 0.35 toe/ habitant in 2002 to 0,45 toe/ habitant in 2007 where electricity consumption per habitant was increased from 469 KWh/ habitant in 2002 to 685 KWh/ habitant in 2007.

	2002	2003	2004	2005	2006	2007
PIB	7%	7%	7%	7%	7%	7%
Consumption (Mtep)	10,5	10,9	11,5	12,3	13,1	13,6
Consumption (tep/habitant)	0,35	0,36	0,38	0,41	0,43	0,45
Consumption (kWh/habitant)	469	509	543	590	642	685

Table 5. Prime energy and electricity consumption in Morocco (2002 – 2007)

Analysis of the historical electric power consumption of the different sectors in 2006 indicates that the industrial sector consumption represents 70.43% of the total consumption, also the agricultural sector consumption represented 6.38 of the total consumption .

Sector	Consumption (GWH)	Percentage (%)
Administrative	714.2	3.48
Agriculture	1310	6.38
Industry	14466.23	70.43
Houses	2905.95	14.15
Transport	1143.7	5.57
TOTAL	**20540.08**	**100**

Table 6. Electricity consumption by sector in 2006

The total electricity installation reached 5 283 MW in 2006 , among which 3489 MW is produced by the national office of Electricity and 1 794 MW by prived operators. Most of the plants consists of thermal power (3 561 MW), by hydroelectric power stations, by Transfer of the Energy (Pumping plant (STEP)) and bywind farms (114 MW).
The total energy called in 2006 was 21.105 GWH, which represent 8,1 % of growth per year.

2.2.1.2. Forecast of electricity consumption for industries

A- High Scenario : reference

Hypothesis:

- Population in 2030 : 40 millions (65% urban)
- Economic growth : 6% between 2000 and 2010
  5% between 2010 and 2020

4% between 2020 and 2030

B- Low Scenario : reforms

Hypothesis:

- Population in 2030 : 40 millions (65% urban)
- Economic growth : 5% between 2000 and 2010

  4% between 2010 and 2020

  3% between 2020 and 2030

2.2.1.3. Forecast of evolution of electricity and primary energy consumption

A- Demand of energy in 2030 (high scenario)

- Primary energy : 105 Mtoe
- Electricity : 133 000 GWh
- Consumption / person : 2.6 toe/year

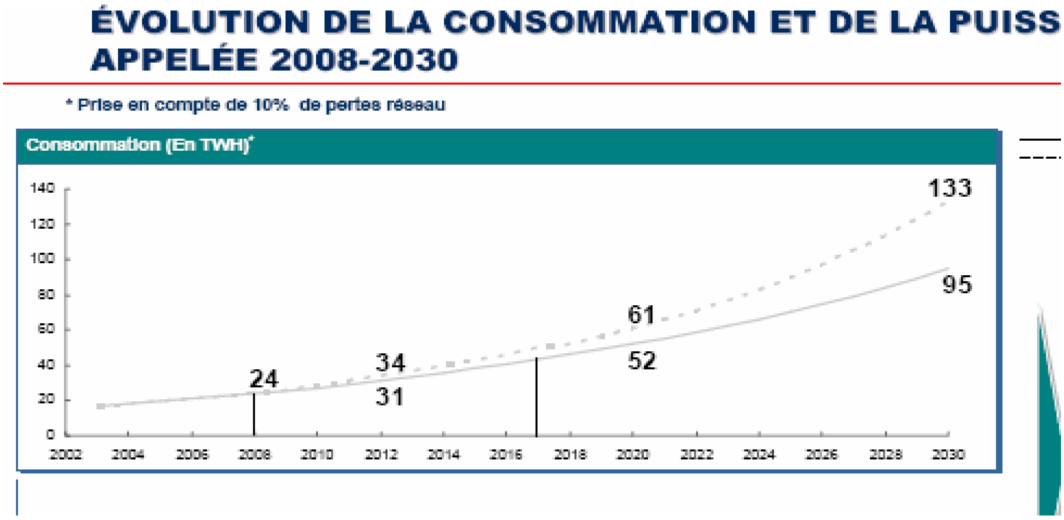


Fig.4. Forecast Evolution of energy generation and consumption 2008 -2030

B- Demand of energy in 2030 (low scenario) :

- Primary energy : 73 Mtoe
- Electricity : 95 000 GWh
- Consumption / person : 1.7 toe/year

Table 7. Forecast evolution of the consumption of electricity (low scenario)-2030

Year	1971	1980	1992	2000	2020	2030		1971	2000	2020	2030
Total of electricity consumed (TWh)	2	5	10	14	52	95	**Total of electricity consumed / person (kWh/p)**	152	497	1270	2375

2.2.1.4. Forecast of evolution of electricity and primary energy installation

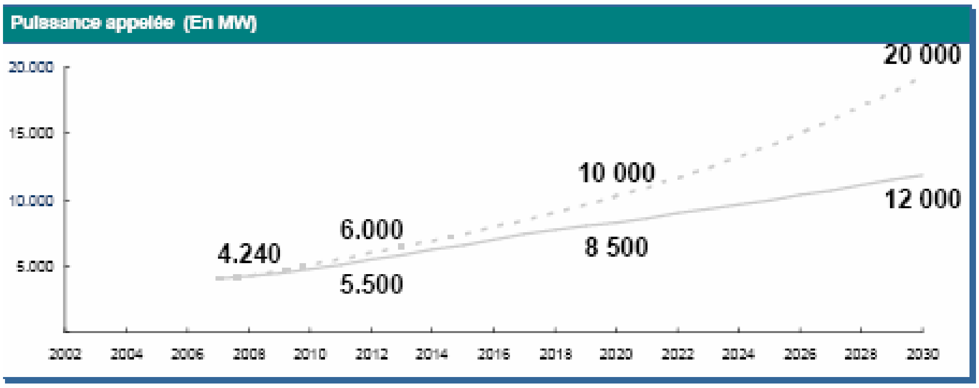


Fig.5. Forecast evolution of the electricity installed 2008-2030
(High and low scenarios)

2.2.1.5. Forecast of the evolution of cooling capacity for food and agro industries

Table 8. Forecast Evolution of the cooling installed capacity 2007-2030

year	1999	2000	2002	2004	2005	2006	2010	2015	2020	2030
Total Power- kW	1 825	2 291	2 777	6 074	9 141	10 412	14625	20112	28580	42880

2.3 Strategic study of Egypt

The study was carried out by the Egyptian Environmental Affairs Authority (EEAA), which is also the steering agency for the studies.

The study covered all of the methodology's issues. The synoptic and forecast analysis for FAI and of the fuel price 2006 – 2030 served to draft part of the "FAI Energy sector Profile and Projections " of the other two national studies

To conduct the study as per the proposed methodology, the EEAA called upon professional establishments:

- Professional association of the Cold sector
- Ministry of Industry and Trade
- Ministry of Electricity and Energy

Introduction: strategic overview

After having analysed the sector of Food and Agro Industry (FAI) in Egypt, the scope of this report is to determine the potential of penetration of the solar cooling in this FAI sector, evolution of energy consumption in (2007-2030) and Evolution of the cooling technology for the same period.

The demand & energy forecast is an alternate to foresee the quantities of electric energy needed by different food industries sector at different times.

This report will develop consumption forecast methodologies and models for food and agro industries . This forecast will be developed based on the econometric method to forecast the energy consumption demand as a function of economic and demographic variables.

Regression analysis (based on historical data) will be used to relate the total energy consumption as a dependent variable to a set of independent or explanatory variables, i.e. the total electricity consumption to one or more of the different econometric factors as Gross Domestic Product (GDP), GDP/sector, Population (POP) and the electricity price.

2.3.1. Steps Taken to Produce the Forecast

2.3.1.1 Analyses of Historical Data

Analysis of the historical electric power consumption of the different sectors during the period 1981/1982 to 2005/2006 indicates that the industrial sector consumption has decreased from

55.4% in fiscal year 1981/1982 to 35.52% in fiscal year 2005/2006 of the total consumption, also the agricultural sector consumption has decreased from 5.1% in fiscal year 1981/1982 to 4.03% in fiscal year 2005/2006 of the total consumption.

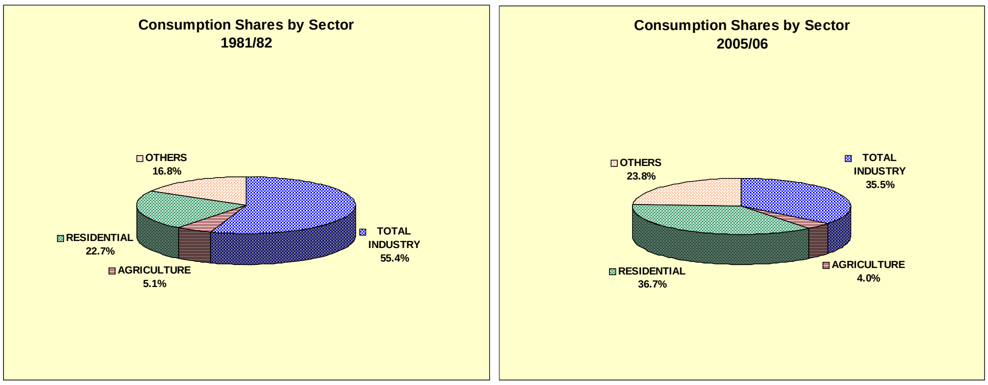


Fig.6. Egyptian energy consumption from 1981/82 to 2005/06 by consumer sectors
Source: Egyptian Electrical Holding Company (EEHC), 2006

Analysis of the Egyptian economy represented by Gross Domestic Product (GDP) [total and per sector] reflected a strong correlation with the electric power consumption.

The Egyptian economy grew rapidly during the decade following the first oil price rise (1974-1986). The GDP has grown at an average annual rate of 7.17% during the period 1981-1986 due to many factors including oil exports, Suez Canal revenues and workers remittance. This high growth rate has slowed down until it reached the level of 1.98% in fiscal year 1991/92 and then started to pick-up again recently, due to the country policy of encouraging investment by the private sector.

The total energy consumption growth has generally mirrored the economy. The growth rates of the total energy consumption and peak demand have increased to reach 10.4% and 9.5 % respectively in the interval 1981-1986. These high growth rates have slowed down until they reached the level of 5.7% and 4.5 % in the interval 1987-1992. They continued to slow down for the total energy consumption and increase for the peak load and reached the level of 5.5% and 5.1% respectively in the interval 1992-1997. In marked contrast, the growth rates of the total energy consumption and peak demand started to pick-up again recently and reached 7.1% and 7.6% respectively in the interval 1997-2002.

Rising population and food needs have resulted in an increase in the AFI's energy consumption, which stands at 18% of total industrial consumption.

2.3.1.2. Forecast of electricity consumption of industries

Hypothesis

In 2006, the Egyptian Electricity Holding Company (EEHC) prepared demand projections for the period from 2006/2007 to 2029/2030 for three scenarios (high, medium, and low). Six assumptions were considered while conducting our FAI forecast calculations, these assumptions are:

1. The demand for electricity within a community is dictated by the absolute number of

potential consumers in the community. The first step in this calculation is a forecast of the total population over the study period. The forecast is made based on an overall 3% population growth estimate.

2. EEHC assumed that the respective annual growth rates for the high, medium and low scenarios for the yearly electricity consumption during the period from 2006/2007 to 2029/2030 are 5.89%, 5.64% and 5.56%. So we assumed that the annual growth rates for the natural gas consumption will be the same as the electricity consumption for the high, medium and low scenarios respectively.
3. The third assumption regarding the conventional fuel driving the thermal power plants where no coal or heavy fuel (Mazot) are used and only the natural gas is used (current situation is 90% of power plants are driven by natural gas).
4. The respective annual growth rates for the high, medium and low scenarios for industry are 6.22%, 5.22% and 4.22 %.
5. The fifth assumption was the average share of FAI electricity consumption is 12.0%, 11.5%, 10.0.1% of the total industry consumption for the high, medium and low scenarios. These percentage values were based on the actual value registered during the period 2001/2006 and illustrated in the 2006 annual report of EEHC.
6. The last assumption was the share of FAI cooling consumption share to the total electricity consumption of industries based on the results of the 15 surveyed companies detailed in deliverable 1.1. It was observed from the conducted survey that about one half of the FAI electricity consumption is used for cooling production, so we fixed the share of cooling consumption to 0.56, 0,53 and 0.50 for the high, medium and low scenarios.

2.31.3. Forecast of evolution of electricity and natural gas consumption of industry

Tables 1,2,3 show both the total electricity consumption forecast in giga watt-hour (Gwh) and its equivalent in million ton oil equivalent (Mtoe) and the total natural gas consumption in billion m^3 and its equivalent in million ton oil equivalent . The high, Medium and low scenarios indicate that the country will consume on 2008/2009 45 million TOE of primary energy including 10 million TOE of electricity increased 0n 2029/2030 to 147, 140 and 138.6 million TOE of primary energy including 32.7, 30.4, 29.3 million TOE of electricity respectively. Also we prepared the demand projections for the period from 2008/2009 to 2029/2030 for three scenarios (high, medium, and low) for the total industry consumption.

Tables 4, 5, 6 present the forecast of the evolution of electricity and natural gas consumption of industry during the period from 2008/2009 to 2029/2030. The total industry prime energy consumption was varying from 12.76, 12.6, and 12.3 Mtoe on 2008/2009 to 45.04, 36.44, and 29.15 Mtoe on 2029/2030 for the high, medium, low scenarios respectively.

2.3.1.4. Forecast of electricity consumption for food and agro industries

Tables 7, 8, 9 show the forecast of the evolution of electricity and natural gas consumption of food industries during the period from 2008/2009 to 2029/2030. The high, medium and low scenarios indicate that the food industries will consume on 2008/2009 1.53, 1.45 and 1.35 million TOE of primary energy including 0.44, 0.40 and 0.35 million TOE of electricity increased to 4.59, 3.43 and 2.59 including 1.33, 0.95 and 0.67 Mtoe on 2029/2030 respectively

2.3.1.5. Forecast of cooling electricity consumption for food and agro industries

The high, Medium and low scenarios represented in tables 10, 11 and 12 show that the cooling production will consume on 2008/2009 2880, 2475 and 2045 Gwhr increased on 2029/2030 to 8391, 5856 and 3920 Gwhr respectively .

From the D1.1 survey we found that the average annual operating hours are 6600 hours and if we consider the coefficient of performance of all refrigeration chillers about 2, these electricity consumption values are equivalent to cooling production of 248634, 214251 and 177067 ton refrigeration on the year 2008/2009 increased to 724426 TR, 507040TR and 339399 TR on the year 2029/2030 as represented in tables 13, 14 and 15 respectively.

2.3.1.6. Forecast of primary energy saving achieved by the implementation of Solar Cooling for food and agro industries

To evaluate the solar cooling systems that could be penetrated into the local market to satisfy the cooling needs of the main activities of food and agro industries, we considered that there is no solar cooling system already operating in the local market on the year 2008/2009 but if we assume that the annual growth rate will yearly increase by 200%, 180% and 160% we shall find on the year 2029/2030 that the capacity of the penetrated solar cooling systems is ranging from 38686TR (low), to 458937TR(medium) to 419304TR(high) as shown in tables 16,17 and 18.

Translating these values to primary energy saved by solar energy, we found that the electricity saved on 2029/2030 is 48444 Gwhr, 5301Gwhr and 446.8Gwhr which are equivalent to 4.16 Mtoe, 0.456 Mtoe and 0.038 Mtoe respectively.

Referring to table1 we found that the total electricity consumption on 2008/2009 is estimated to be 10 million toe which is about two and half times the primary energy saved by solar energy cooling on 2029/2030 which is 4.16 Mtoe as presented in table 16, this give us a clear picture regarding the high potential of FAI solar cooling applications in reducing the electricity consumption for cooling needs as they are constantly growing and representing the main component of the electrical grid loads during summer in Egypt. The reduction of peak loads corresponds to a reduction of power demand to the electrical grid and thus , in long terms, to the reduction of the costs (both economically and environmentally) of electricity production, transmission, distribution and delivery. It is evident that solar technologies are particularly suited for this scope as higher solar radiation and duration correspond to higher cooling needs.

2.4 . Summary of Forecast Results

All the considered assumptions and the details that describe the steps taken to project energy consumption, energy generation, peak load and the share of FAI for the three scenarios as well as final results of the forecast model are shown in the next tables.

Table 9. Synoptic table of the industry energy consumption forecast in Tunisia, Morocco and Egypt

		MOROCCO				EGYPT				TUNISIA			
		2008		2030		2008		2030		2008		2030	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Industry Energy Consumption Forecast	Total natural gas Cons. (billion m3)	0.65	0.65	14.6	21	40.1	40.1	125.3	131	2.481 mtoe	2.481 mtoe	4.11	4.382 mtoe
	Total electricity Consumption(Gwh)	24100	24582	95200	133200	109365	109365	340387	379877	11249	11249	18758	19977
	Industry natural gas cons.(billion m3)	0.06	0.06	0.807	0.99	10.43	10.43	24.7	36.82	0.894 mtoe	0.894 mtoe	1.48 mtoe	1.58 mtoe
	Industry electricity Consumption(Gwh)	17111	20533.2	67592	94572	42856	42856	96919	151353	4062	4062	6774	7214

Table 10. Synoptic table of the FAI energy consumption forecast in Tunisia, Morocco and Egypt

		MOROCCO				EGYPT				TUNISIA			
		2008		2030		2008		2030		2008		2030	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
FAI Energy Consumption Forecast	Industry natural gas cons (Mtoe)	0.607	0.73	0.81	1.38	9.10	9.10	21.58	32.02	0.894	0.894	1.48	1.58
	Industry electricity consumption (Mtoe)	0.607	1.76	8.18	11.45	3.69	3.69	7.58	13.02	0.505	0.505	0.84	0.89
	FAI natural gas cons (Mtoe)	0	0	0	0	0.91	1.09	1.77	3.27	0.05	0.05	0.06	0.06
	FAI total electricity consumption (Mtoe)	0.33	0.39	1.3	1.81	0.37	0.44	0.62	1.33	0.08	0.08	0.10	0.11

Table 11. Synoptic table of the FAI Solar Cooling Savings Forecast in Tunisia, Morocco and Egypt

		MOROCCO				EGYPT				TUNISIA			
		2008		2030		2008		2030		2008		2030	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
FAI Solar Cooling Saving Forecast	FAI total electricity consumption (Gwh)	3832	4600	15140	21184	4165	5143	8016	14984	372	372	457	487
	FAI electricity cons. of cooling systems (Gwh)	2070	2484	8175	11440	2082	2880	4008	8391	208	208	256	273
	FAI cooling Systems capacity (TR)	181952	223801	280000	344400	540860	745901	433732	2173279	54062	54062	27710	70624
	FAI Solar Cooling Systems (TR)	0	0	11200	13776	0	0	24178	81284	0	0	836.68	12089
	FAI Solar Cooling Savings(Gwh)	0	0	41	52	0	0	93	313	0	0	0.148	46.54
	FAI Solar Cooling Savings(Mtoe)	0	0	0.0035	0.0044	0	0	0.008	0.027	0	0	0.00001	0.004

Recommendation

Since there are some uncertainties in the load and energy demand forecast due to external factors such as world trade organization and Gatt rules of liberalization, competition, effect of globalization and current world financial cries on export growth, volatile financial markets affecting direct investment...etc., and their effects on the level of industrial and agricultural growth and consequently the future electricity and natural gas demand, the medium scenario is chosen to be used for energy generation and consumption expansions and tariff studies.

VOLUME 3. FUEL PRICE PROJECTIONS

Fuel price projections are one of the key hypothesis of the Study. Fuel prices directly impact the profitability of the solar cooling systems. High fossil fuel prices will increase the attractiveness of solar cooling with respect to conventional cooling, while low fuel price might turn the solar cooling non profitable.

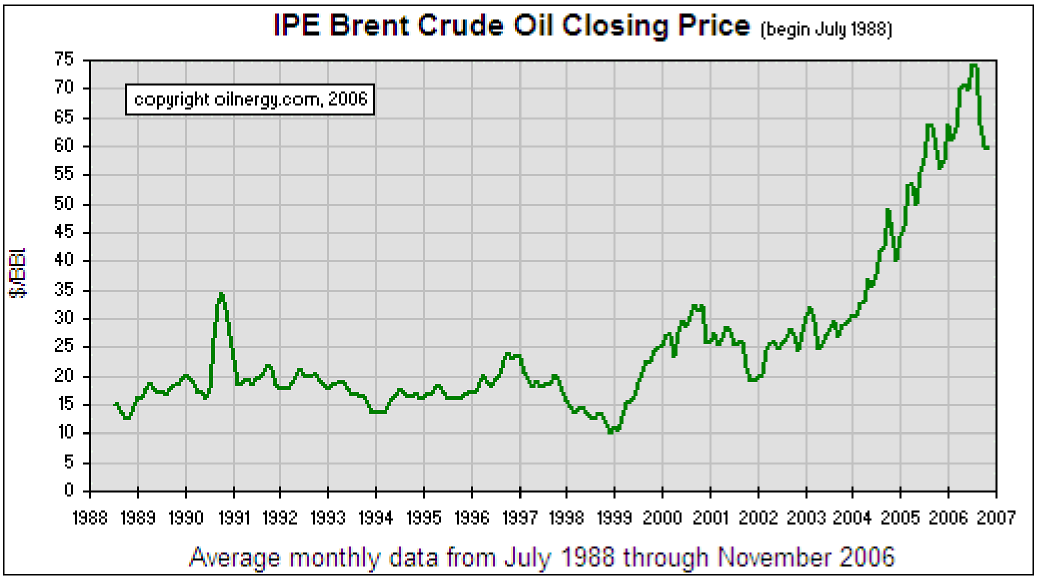


Fig.7. : Historical price of Brent crude oil

The evolution of the oil market price is mainly driven by different factors:

- evolution of the world oil demand (depending on oil intensity in the economy and on economic growth of major consuming nations) ;
- global supply of oil, in Organisation of the Petroleum Exporting Countries (OPEC) and non OPEC countries, which is itself linked to the market price (higher prices encourage exploration and exploitation of more expensive resources) ; investments in the development of new production capacities ;
- evolution in the proven and ultimate reserves, and estimated time for peak oil when demand will outbalance the supply ;
- production costs for conventional and unconventional oil ;

A number of international institutions, organisations or analyst groups, regularly update projections of long term oil prices. For example:

- International Energy Agency (publication: World Energy Outlook),
- European Commission(publication: European Energy and Transport, Trends to 2030)
- Organisation of the Petroleum Exporting Countries(publication: Oil Outlook to(2025)
- US Department of Energy, Energy Information Administration (publication: Annual Energy Outlook 2006)
- World Bank,
- Major Utilities (EDF, etc)

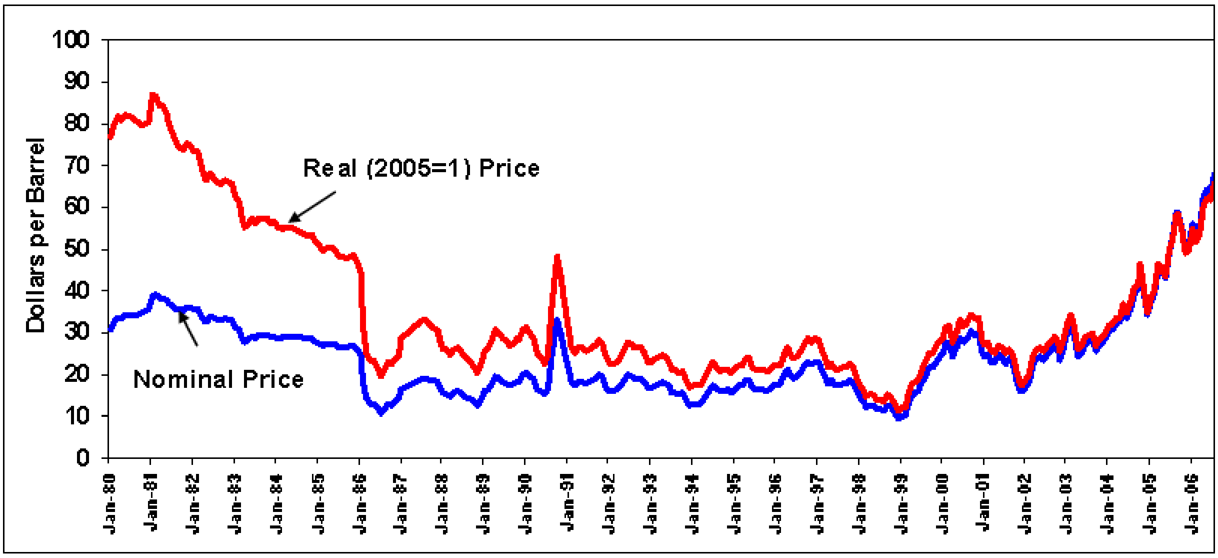


Fig.8. : Historical oil price evolution from 1980

Reference : Energy Information Administration

The most recent projections might show some variations on the actual values from one institution to another but there is a consensus agreement over the general evolution of the oil price:

<u>Phase I : oil price declines in the short term</u>:

The average world oil price declines slowly from the current level (60-70 USD/bbl) to a minimum value in 2015, as new supplies enter the market, as well as substantial development of unconventional production,

<u>Phase II : price rises through 2030</u>:

The increase of the world oil price from 2015 reflects the rising costs for the development and production of non-OPEC oil resources with the approaching forecast peak oil, timed between 2020 to 2030 depending on scenarios.

Prospect for oil price remains extremely uncertain. It is interesting to note that in all available projections the differences between high and low scenarios have increased significantly compared to past year projections. This is a testimony to the growing uncertainties.

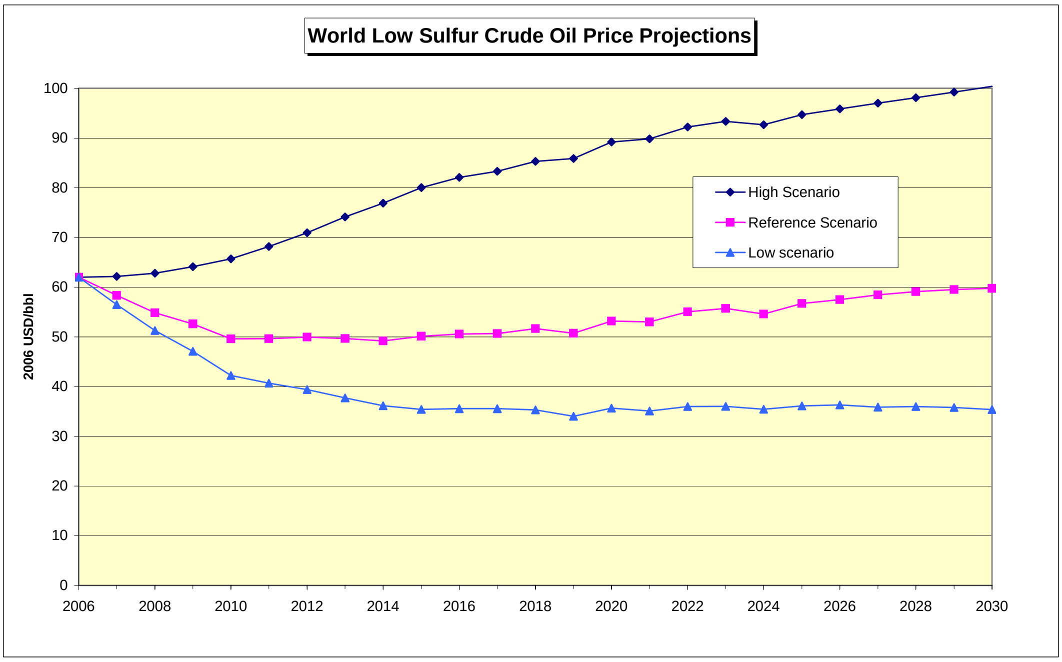


Fig. 9. World Oil Price Projections

We found relevant to use the following international fuel price projections:

- Oil price projections from the Energy Information Administration (AEO 2006):

Unit : 2006 USD/bbl

Scenario	2006	2007	2008	2009	2010	2015	2020	2025	2030
High	62.0	62.2	62.8	64.1	65.7	80.0	89.2	94.7	100.4
Refrence	62.0	58.3	54.9	52.6	49.6	50.1	53.2	56.7	59.8
Low	62.0	56.5	51.3	47.1	42.3	35.4	35.7	36.1	35.4

Table 12 - Oil price projections

- Natural gas projections from the European Commission for the European and African market:

Unit : USD_{2006}/MBTU

Scenario	2006	2010	2015	2020	2025	2030
High	6.5	6.4	7.4	7.9	9.0	10.5
Reference	6.5	6.4	6.4	7.0	8.1	8.4
Low	6.5	4.8	4.9	5.0	5.1	6.6

Table 13 - Natural gas projections

VOLUME 4. REVIEW OF THE SPECIFIC LEGISLATION, POLICY MECHANISMS AND FINANCIAL SCHEME ABLE TO EASY SOLAR COOLING PENETRATION

The market and institutional barriers facing the penetration and integrating renewable energies in the agro-food industry in Egypt were identified through the on- site interviews conducting within the questionnaire and survey included in WP1. These barriers are:

1. Lack of the user awareness.

The conducted survey provided the companies vision regarding how solar energy cooling projects can save money. Because only a few of host companies regularly receive visitors, end – users awareness of the benefits of solar cooling application is limited. Without widely disseminating the saving results and efficiency gains the success of these projects can not over com the perception that energy efficiency and solar cooling projects are not cost effective.

An apparent disconnect also exists between the potential saving of solar cooling applications and end – users participation of which applications will most help them save energy. There is disconnect between energy saving opportunities and end – users awareness. In addition, some commercial and industrial end – users believe that reducing energy consumption is incongruent with expanding the output of their plants , plant mangers and / or owners reported that their top investment priority is the expansions of product quality.

2. Organizational barriers

Communication channels between company management and plant engineers in both private and public sector companies are typically poor, without an ongoing dialogue between companies owners and plant engineers, potential gains in efficiency can be lost, in public sector companies, the complexity of the procurement process is another organization barrier, this procurement system becomes prohibitively complex when the purchase of new technologie for foreign manufactured equipment is requested, companies in the survey identified the lack of solar energy services as a major barrier: there is no available assistance with solar cooling identification, installation and implementation and the majority of applications with the greatest saving potential. These results confirm the need for an array of solar energy management services.

3. Operation and maintenance practices:

The interviews results indicate that there are not enough skilled technicians to operate and maintain solar cooling equipment. In addition, end users typically will not be able to follow standard preventive maintenance practices, limiting the success of solar energy projects without in. End -users focused heavily on after- sales support from equipment vendors, since the market for solar energy is still developing many equipment vendors do not have the local infrastructure in place to provide extensive after- sale services, the availability of spare parts is also essential to the proper operation and maintenance of solar cooling equipment. The Survey respondents indicate that obtaining spares parts for equipment used in solar cooling applications is difficult, the lack of locally available spare parts is a disincentive to investing in solar cooling given the high costs associated with delays in production.

4. Energy efficiency Equipment Import Barrier:

High import duties are often assessed on solar energy equipment because customs officials often deem that a locally manufactured alternative exist, high duties on equipment raise the effective cost of solar energy investment, however, those import rulings do not accurately account for the different efficiency levels of the local and foreign manufactured equipment.

5. Financial barriers:

Investments in renewable energy applications are affected by both commercial banks and end users lack of experience in financing renewable energy projects. Companies interviewed in the survey indicated reluctance to finance investments with bank loans, preferring instead to develop projects using operating budgets or specialized shareholder account, this practice, however, prevents end-users from accessing all available funding option for solar energy investments.

These barriers, coupled with end user reluctance to use bank loans, create an environment where there is an inability to access available credit. Investment in solar cooling are also hindered by energy tariffs which, historically, have been heavily subsidized, by setting energy tariffs below world market levels, there is a disincentive to invest in solar cooling because the actual value is not reflected in the price paid by end- users. Artificially low tariffs also increase the payback period on solar cooling investments.

6. Low Cost of natural gas:

The relatively low cost of natural gas has discouraged somewhat the renewable energy efforts because of the resulting higher payback periods in energy efficiency applications.

VOLUME 5: FUTURE DEVELOPMENT OF SOLAR COOLING TECHNOLOGY.

5.1. COLD DEMAND IN AGRO-FOOD INDUSTRY

While several solar cooling technologies can cover the cooling demand at the high temperature range there is a high potential and advantages for cooling at low temperatures due to a significant economy of scale (i.e., refrigeration technologies represent a large share of the investment and operation costs). This implies the need to investigate deeply this market sector in order to ensure that the this sector is fulfilled using solar cooling technology.

5.2. CURRENT SOLAR COOLING TECHNOLOGIES:

All heat, mechanical work and electricity can drive refrigeration machines. The appropriate refrigeration cycle depends on the cooling demand, available form of energy input, and temperature level of the refrigerated objects and the environment. The solar-powered cooling system generally comprises three main parts: the solar energy conversion equipment, the refrigeration system, and the cooled object (e.g., a cooling box). A number of possible “paths” from solar energy to the “cooling services” are shown in figure 10.

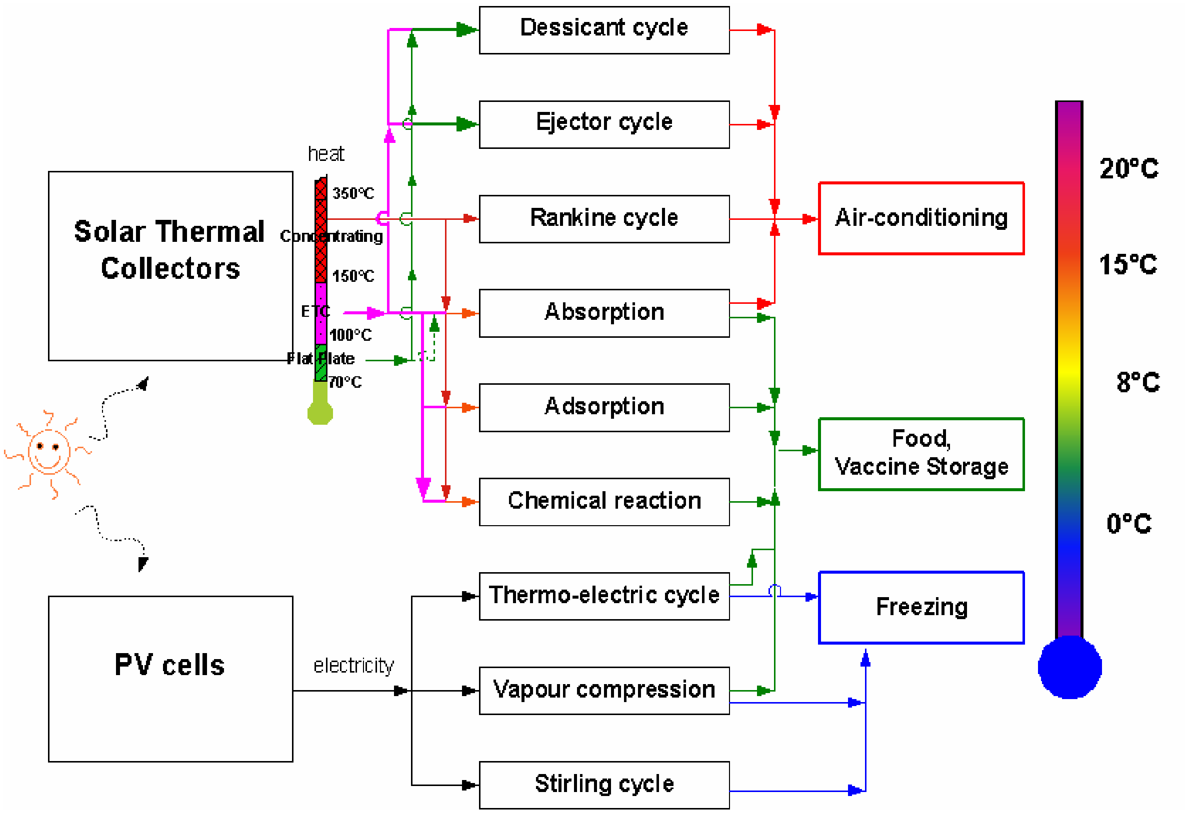


Figure 10. Solar cooling path. [1]

For temperatures of 15-20°C, cooling capacity is generally high and energy removed from the chilled space has a low potential to convert to a useful energy. The solar thermal-driven system is more suitable for the air-conditioning system than the photovoltaic-driven one due to a lower installation cost. Furthermore, the performance of the thermal driven refrigeration machine is high at high evaporation temperatures. The solar thermal-driven air-conditioning system could be the absorption chiller, the adsorption chiller, the desiccant cooling system, the Rankine system or the ejector refrigeration system.

For the low temperature requirement for food storage of 0-8°C, many systems can be applied, e.g., the vapour compression system, the thermoelectric system (Peltier), the absorption system, the adsorption system or the chemical reaction system. For an application that needs temperature below 0°C, e.g., freezing boxes or ice production units, a vapour compression chiller, an absorption chiller, an adsorption chiller, a chemical reaction chiller and a Stirling chiller can be used. Typically the performance of an electricity-driven refrigeration system is quite high but it requires photovoltaic panels, which are expensive and have low efficiencies. But these systems can be built in small sizes, thus making them suitable for small applications such as vaccine transportation or cooling boxes.

The solar-driven refrigeration system is mainly classified in to 2 main groups depending on the energy supply: thermal/work driven system and electricity (Photovoltaic) driven system. Each group can be classified as the following,

5.2.1. Thermal/work driven system

- ABSORPTION REFRIGERATION CYCLE
- Adsorption refrigeration cycle
- Chemical reaction refrigeration cycle
- Desiccant cooling cycle
- Ejector refrigeration cycle

EXPANSION REFRIGERATION CYCLE

5.2.2. Electricity (Photovoltaic) driven system

- **Stirling refrigeration cycle**
- **Thermo-electric refrigeration cycle**
- **Vapour compression refrigeration cycle**

Table 14: Existing solar-driven refrigeration systems [1]

Thermal-driven systems				***Applications***	
Systems	**Gen./ Regen. Temp. (°C)**	**COP_{cycle}^{c}**	**Working Fluid**	**Refrigeration**	**A/C**
Absorption	80-190	0.6-0.8 (single stage) ≤ 1.3 (2 stages)	NH_3/H_2O, $H_2O/LiCl$, $H_2O/LiBr$	✓	✓
Adsorption	80-300	0.3-0.8	H_2O-Zeolite, Methanol-Activated Carbon	✓	
Chemical reaction	80-300	0.1-0.2	$NH_3/SrCl_2$	✓	
Duplex-Rankine	>120	0.3-0.5	water, R114, Toluene, Organics fluid		✓
Desiccant	40-100	0.5-1.5	water		✓
Ejector	80-150	0.3-0.8	water, butane, R141b, etc.		✓

Electricity-driven systems				***Applications***	
Systems	**Power for 1 W of the cooling effect (W)**	**COP_{cycle}^{c}**	**Working Fluid**	**Refrigeration**	**A/C**
Vapor-compression	12-50	3 - 5	R134a, R290, etc.	✓	
Thermo-electric	a few W	0.5^{a}	-	✓	
Stirling	3 - 17	3^{b}	He, H_2, N_2	✓	

Remarks: ***a**;* International Institute of Refrigeration (IIR), (1999)., based on the sunlight of 5 kWh/m^2 day

a*;* International Institute of Refrigeration (IIR), (1999)., based on the theoretical calculation of ETC solar collector surface of 1.8-1.2m^2/kWh day, chilling at –5°C and condensation temperature at 35°C.

***b**;* Globalcooling, (2001)

c; COP of the refrigeration sub-system.

5.2.3. SOLAR THERMALLY AND ELECTRICALLY DRIVEN CHILLERS:

The advantages of thermally driven chillers compared to electrically driven vapour compression chillers include the following:

1) Maintenance costs are lower as there are fewer moving parts.
2) Operation costs are lower as electricity consumption is very low (around 1% - 5 % of chilled water capacity).
3) Performance is higher in nominal conditions at a partial load.
4) The substances used are absolutely safe environmentally (water, lithium bromide, ammonia, silica gel).

These advantages of thermally driven chillers lead us to explore more this area.

5.2.4. THERMALLY DRIVEN CHILLERS:

Thermally driven chillers may be characterized by three temperature levels:
- a high temperature level at which the driving temperature of the process is provided;
- a low temperature level at which the chilling process is operated;
- a medium temperature level at which both the heat rejected from the chilled water cycle and the driving heat have to be removed. For this heat removal, in most cases, a wet- cooling tower is used.

Basic scheme of the process is shown in Fig 11 : Qcold is the heat rejected from the chilled water in the evaporator of the chiller (chilling power), Qheat is the required heat in the generation part to drive the process, and the amount of Qreject , the sum of Qcold and Qheat , has to be removed at a medium temperature level TM. Qheat is delivered either by the solar system or by backup heat sources, e.g. by district heat or by a gas burner [2].

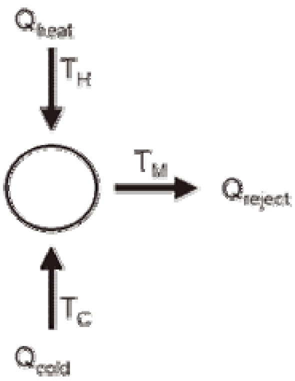


Figure 011 Basic process scheme of a thermally driven chiller [2].

The main equipment types in the category of thermally driven chillers are absorption, adsorption and desiccant system,

While the first two technologies mentioned (absorption and adsorption) are considered as closed systems (the cooling medium is not in direct contact with the environment), the third technology (Desiccant) is considered as open process where the cooling medium comes into direct contact with the air being conditioned.[3]

The present document has not considered the open systems due to they are specially applicable on air-conditioning plants. The application of solar cooling in agro-food processes leads to the use of solar resource at different temperature levels, from -5ºC to 15 °C. In that sense, we have focused on the description of the technology in closed systems since they fit better in this variety of different uses of solar heat.

In the following table, the principal market features of closed system thermally driven chillers are summarized.

Table 24 Thermal driven chillers main features for present market [4]

process	absorption		adsorption
stages	single effect	double effect	single effect
ab/adsorbent	lithium bromide / water (1)		silica gel
refrigerant	water / ammonia (1)		water
generator T.	80 ºC – 110 ºC	140 ºC - 160 ºC	60 ºC – 95 ºC
flow	hot water or overheated water	overheated water or steam	hot water
COP	0.6 - 0.8	0.9 – 1.2	0.4 – 0.7
market capacity	< 35 kW incipient market 35 kW to 100 kW few manufacturers >100 kW wide market	>100 kW wide market	< 50 kW (Sort.) 50 – 350 kW (May.) 70 – 1220 kW (Nis.)
manufacturers	Climatewell, Rotartica, Sonnenklima, Schucö, Yazaki, Broad, EAW, Carrier, Trane, York, LG Machinery, Sanyo-McQuay, Entropie, Thermax, …		Sortech, Mayekawa, Nishiodo
suitable solar collector	selective flat-plate evacuated tube stationary CPC	parabolic trough	selective flat-plate evacuated tube stationary CPC

(1) Pair of absorbent /refrigerant are as in the same order as indicated

The main advantages of adsorption chillers compared with absorption chillers are as follows:

1. The operating temperatures at the generator can be lower: from 60 ºC to 90 ºC in adsorption, compared to 90 ºC to 120 ºC in single effect absorption chillers.
2. There is no lower limit to the cooling water temperature in the back-cooling system as there is no danger of crystallization.
3. Changes in the COP are not so dependent of the generator water temperature or cooling water temperature as in the absorption chillers (see picture below).

On the other hand, the main disadvantages of adsorption chillers compared with absorption chillers are as follows:

1. 1. The average COP of the adsorption equipment is worse in comparison with absorption equipment.
2. 2. The equipment in the market at present is both larger and heavier than comparable single effect absorption chillers.
3. 3. Adsorption equipment is more expensive.

5.2.5. TYPES OF THERMALLY DRIVEN CHILLERS:

Rearranging the information gathered from the surveys and the analysis followed lead us to focus on particular solar thermally driven cooling technology more than the others. This is the absorption technology.

The main reasons for this selection are:

1. Gas fired absorption technology is commercially available in the local markets of Egypt, Morocco and Tunisia.
2. The energy status and forecasting for the local markets showed a high trend toward utilizing natural gas fired absorption chillers at the expense of electrically powered vapour compression chillers. This is due to the low natural gas prices and thus the cost

of cold produced. And this can be a key market to introduce solar thermally driven chillers, and hybrid gas-solar thermally driven chiller. The market analysis in Egypt showed that “the number of absorption-refrigeration units have been doubled between 2004 and 2005, at the expense of compression-refrigeration units”.

3. Absorption technology can serve the cooling demand at low temperature not only when powered by gas, but also when driven by the heat produced by medium temperature collectors such as parabolic and Fresnel collectors.

5.2.6. THERMALLY DRIVEN ABSORPTION CHILLERS:

As for now, we are focusing on the absorption technology, we need to describe in detail this technology, and the barriers of using solar energy with this type of systems. as well as investigate possibilities in order to give in the short medium term the possibility to develop appropriate solar driven system components.

THE TECHNOLOGY.

The basic absorption chiller (AcCh) system is schematically shown if Fig.12 showing the major components; The condenser, cooling medium expansion valve and evaporator from the cooling part of the system, through which only the cooling medium flows. The thermal compressor comprises absorber, solution pump, generator and solution throttle valve, constituting the driving part of the system.

The cooling part of the AcCh is no different from the conventional compression chiller. The necessary compression of the cooling medium to the condenser pressure is performed by the thermal compressor. The vaporized cooling medium flows into the absorber, where it is absorbed by the solvent. The released absorption enthalpy must be dissipated, as the absorption capacity of the solvent decreases as the temperature rises. The absorption process enriches the absorption medium with cooling medium. The rich solution is pumped using the solution pump to generator (also known as a de-aerator or boiler). Here, by supplying thermal heat, the cooling medium is separated from the solvent and the two-substance mixture becomes depleted of cooling medium. The depleted solvent is depressurized in the solution throttle valve to the absorber pressure where it once again atomized in order to absorb the cooling medium.

Apart from the electrical power requirement of the solution pump, the AbCh is driven only by thermal energy. However, the energy requirement of the solution pump is very low, with approximately 0.5-2% of the refrigeration capacity achieved in the evaporator.

The efficiency of AbCh shown in Fig.2.4 is usually improved by installing a solvent heat exchange. This is arranged so that the rich, cold solution after the absorber and the warm, depleted solution after the generator flow in opposite directions through the heat exchanger. This makes possible saving on thermal heat in the generator and on cooling water in the absorber [3].

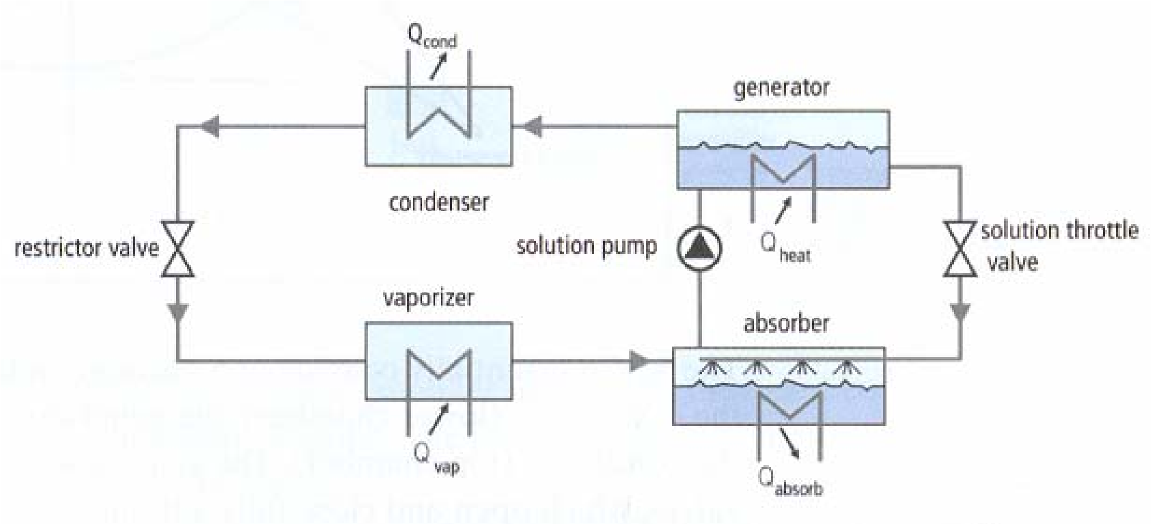


Figure 012 Absorption system components. [5]

5.3. Hints for applying solar cooling in agro-food sector:

The available solar cooling installations are commonly based on hot water-driven single effect absorption chillers. This configuration yields a considerable solar cooling performance when solar heat is applied as driving heat source only. However, in industrial agro-food installations requiring reliable supply of cooling with no regard to the current availability of solar driving heat, for this reason there is the necessity of using a back-up system, this could be compression chiller or fossil fired boiler:

a. Fossil fired boilers are applied as back-up heat source:

Generally, in order to limit the system first cost a substantial share of the annual cooling load has to be contributed by the backup operation. According to the thermal efficiency of the absorption chiller the energy saving during solar operation may be over-compensated by the driving fossil energy demand during backup operation.

b. Mechanical vapor compression chiller:

This is a possible solution to overcome the previous problems. This is particularly appropriate when solar cooling fraction is low. It can operate in parallel or in series with the absorption chiller, depending on the demand profile and the user requirement.

A rough analysis of the primary energy demand of the solar assisted cooling system shows that for a standard absorption chiller (Coefficient of Performance, COP = 0,75) a minimum solar fraction of 40% to 70%, depending on the coefficient of performance of the reference system (i.e. 100% compression cooling with COP = 3…6) has to be accomplished. In the case of a two-stage absorption chiller with COP = 1,3 a substantially lower solar fraction is required to achieve overall energy saving.

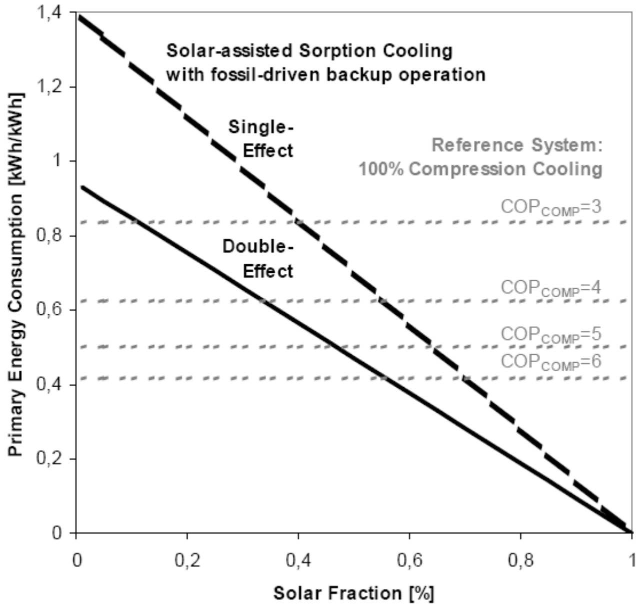


Figure 13: Primary Energy Consumption of solar-assisted sorption cooling systems (with single-effect or double-effect chiller) with fossil-fired backup operation. Comparison with conventional 100% compression cooling. [6]

For the above comparison only the driving energy demand for the chiller without parasitic demand for circulating the heat carriers and for the operation of the reject heat system has been taken into account. The efficiency of power generation has been set to 40% and the burner efficiency of the backup-heater has been set to 95% in the case of the standard single-effect chiller and to 85% in the case of the two-stage chiller due to the higher supply temperature of the backup-heat. [6]

5.4 FUTURE DEVELOPMENT OF SOLAR COOLING IN AGRO-FOOD INDUSTRY:

The main characteristics those are required from a solar cooling system in order to be a market competitor:

1. Guarantee of reliable supply of cooling regardless of the current availability of solar driving heat, as mentioned above, this requires a back-up system.
2. the total primary energy consumption should be lower than conventional systems gas fired and vapour compression systems.
3. The installation cost should be reasonable, basically the additional cost of the solar collector, However, the solar fraction should be high enough to ensure primary energy savings.

Several attempts are ongoing in order to realize systems that fulfil these requirements, even though the aim of these attempts is the same, their approaches are variable, some research is ongoing to improve the COP of the absorption chiller, others are investigating the super-positioning of single effect and double effect absorption cycles, others are focusing on producing high efficiency collectors with lower cost.

An interesting attempt is to apply absorption chillers with two stages and two different entrances for heat, one coming from solar and the other from a boiler, at higher temperature.

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