Study project MED-CSP

Concentrating Solar Power for the Mediterranean Region

Farming Systems under and around Solar Thermal Power and Desalination (STPD) Plants

" Eco-Solar Oasis"

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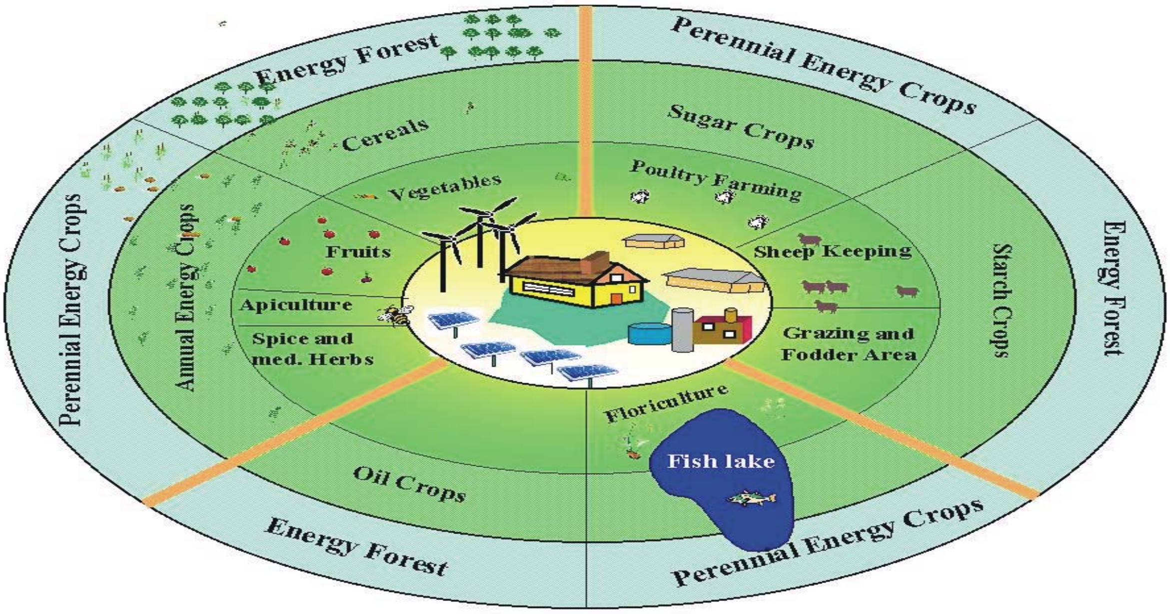
1. INTRODUCTION

Current approaches to energy are unsustainable and non renewable. Furthermore energy is directly related to the most critical social issues which affect sustainable development: poverty, jobs, income levels, access to social services, gender disparity, population growth, agricultural production, climate change and environment quality and economic and security issues. Without adequate attention to the critical importance of energy to all these aspects, the global social, economical and environmental goals of sustainability can not be achieved. Indeed the magnitude of change needed is immense, fundamental and directly related to the energy produced and consumed nationally and internationally.

The key challenge to realizing these targets is to overcome the lack of commitment and to develop the political will to protect people and the natural resource base. Failure to take action will lead to continuing degradation of natural resources, increasing conflicts over scarce resources, widening gaps between rich and poor and promoting the depopulation of rural regions. We must act while we still have choices. Implementing sustainable energy strategies is one of the most important levers humankind has for creating a sustainable world. More than 2 billions people have no access to modern energy sources, most of them are living in rural areas. Sustainable development in rural communities is very closely related to energy availability.

In order to meet challenges, the future energy policies should put more emphasis on developing the potential of energy sources, which should form the foundation of future global

In this context the FAO of the United Nations in support of the Sustainable Rural Environment and Energy Network (SREN) has developed the concept of the optimization, evaluation and implementation of Integrated Renewable Energy Farms (IEF) for rural communities. The IEF concept includes a decentralized living area from which the daily necessities, economic and social activities can be produced and practiced directly on-site (3, 4, and 5).



Model of an Integrated Renewable Energy Farm (RIEF) (© El Bassam, 1998)

Fig. 1: The Integrated Energy Farm (IEF)

The IEF based largely on renewable energy sources would seek to optimize energetic autonomy and ecologically semi-closed system while also providing socio-economic viability (food, water, waste management and employment) and it should consider aspects of landscape and bio-diversity management. Ideally, it has to promote the integration of different renewable energies; contribute to sustainable rural development and to the reduction of greenhouse gas emission as well as improving the living environment.

The Trance Mediterranean Renewable Energy Collaboration and regional energy structure (TREC), an initiative of Club of Rome, has launched 2004 a Project Study “Concentrating Solar Power for Mediterranean Region (MED-CSP)” (8).

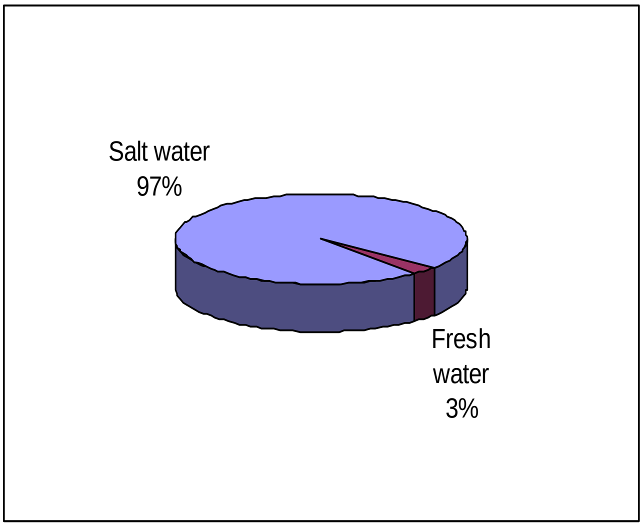
This concept aims at planning, optimizing, designing and building a first plant for solar electricity generation and seawater desalination (POSEIDON), based on concentrating solar thermal power (CSP) technology in a MENA coastal area with arid or semi-arid climate, and to prepare for the replication of this concept in the MENA region and world wide.
Objectives:
The overall task of IFEED in this project is the adaptation of the FAO concept of Integrated Energy Farming in MED-CSP project for rural and agriculture development in Mediterranean

region as well as the identification of revenues and demand structures in agriculture and the rural sector.

II. Water, environment and agriculture: Basic information

The following information explains the interaction effects of various factors (water, genotype, temperatures etc.) on productivity of crops.

1) Only 3% of the world water resources are freshwater, with 2, 31 being fixed in glacier sand permafrost in the poles and not available for consumption and about 0, 69% available in rivers, lakes, soil, swamps, groundwater and vegetation (Fig. 2).



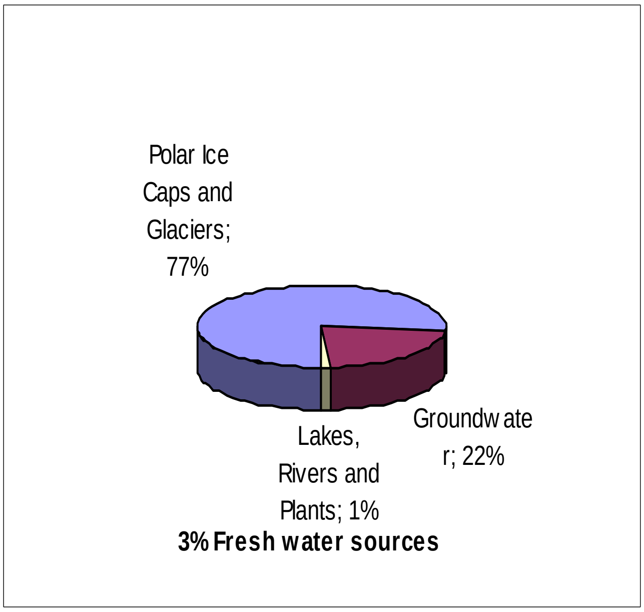


Fig.2: The world water resources (2).

2) Globally about 70% of water is being used in agriculture.

3) Inefficiency in water use worldwide is huge. Losses in conventional irrigation systems are about 50 – 90%. Only 10-50% of irrigation water reaches the crops. The rest evaporates or seeps away.

4) Huge differences exist in water requirements for different food production chains. Fig.3 gives information on water consumption in different plant and animal production cycles.

II.1: Water use efficiency

Water use efficiency (WUE) is an important indicator for water demand of the crops to produce food. It also is used for meat productivity of various animals (beef, sheep meat and eggs). Productive WUE considers only the actual amount of water need in connection with the photosynthesis or transpiration rate which depends on the air temperature and humidity. Considerable water losses are resulted from surface evaporation, percolation and surface flows (1, 2, 8, and 10).

Table 3 reflects the amounts of water in litres required to produce one kilogram (kg) of food as dry matter. It shows clearly that lowest water demand is needed by vegetable crops. Meat production, especially of beef consumes the highest water rate.

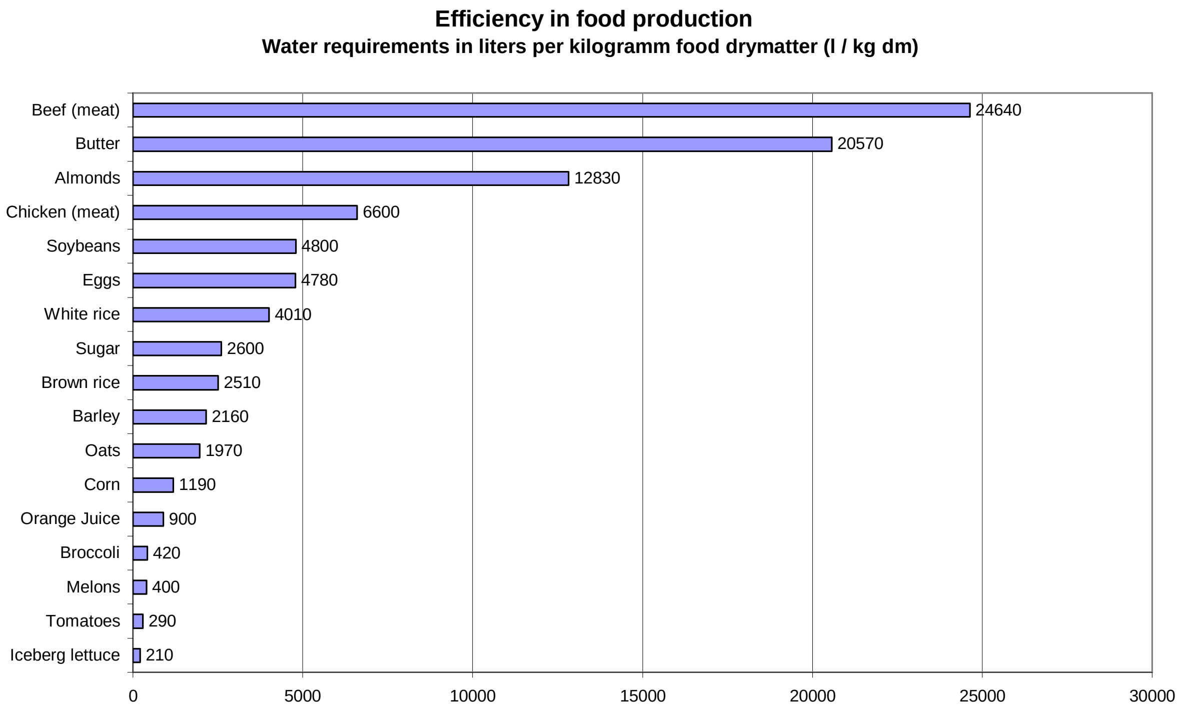


Fig. 3: Water requirements in food production

This project offers the possibility and chance to identify the most effective plant species in water use efficiency, the most effective irrigation system and suitable farming systems for CSP to reduce water demand, to combat desertification and ensure sustainable rural development.

II.2: Environment and plant productivity

The tables 1-4 are essential for the interaction effects of genotypes, light, water and temperatures of the site on yield determination (6, 7).

Table 1: Photosynthesis (mg CO2 / s dw x h) of soil moistures and relative humidity

Field capacity	Relative humidity	
	70%	30%
30%	**16,5**	**14,3**
70%	**8,8**	**6,6**

Table 2: Light intensity under natural conditions

	Quants / m² x s
Day light, clear	800.000
Day light, cloudy	130.000
Day light under plant shade	17.000
Twilight	600
Moon light	0,2100
Star light	0,0009
Night sky, cloudy	0,0001

Table 3: Theoretical upper limit of crop production at 40° Latitude

Total energy radiation (TER)	$1{,}47 \times 10^{1o}$	kcal/ha
Upper limit of efficiency for TER	6,8	%
Average calorific value of biomass	4,00 x 10	kcal/ha
Maximum crop productivity	250	tons

Table 4: Photosynthetic efficiency of a standard crop

Total energy radiation (TER)	$4{,}00 \times 10^{1o}$
Photosynthetically active radiation (PAR))	$1{,}47 \times 10^{13}$
Caloric value (4.000 cal / g)	$6{,}32 \times 10^{12}$

II.3: Potential of plant productivity for biomass and food

The potential growth of plant materials is the results of the interactions between the genotype (genetically fixed potential), environmental constrains (temperature, air humidity, wind velocity and precipitation) and the external inputs (fertilizers, water, chemicals, seeds etc.).

The results of these interactions have been used to classify the major important plant species in 5 main groups I-V (table 6) according to their photosynthetic pathways.

Table 5: Physiological characteristics and requirements of different plant species

Characteristics	**Unit**	**Crop group**				
Photosynthetic pathways		**I**	**II**	**III**	**IV**	**V**
Radiation intensity at max. photosynth.	cal / cm² x min	0,2 - 0,6	0,3 - 0,8	1,0 - 1,4	1,0 - 1,4	0,6 - 1,4
Operative temperature	°C	5 -30	10 - 35	15 - 45	10 - 35	10 - 45
Max. crop growth rate	g / m² x day	20 - 30	30 - 40	30 - 60	40 - 60	20 - 30
Water use efficiency	g / g	**400-800**	**300-700**	**150-300**	**150-350**	**50-200**

Group I C 3 pathway: Field mustard, potato, oat, tomato, rye, grape, rape, pyrethrum, sugar beet, bread wheat, chickpea, French bean, Arabic coffee, sunflower, olive, barley. Cabbage, lentil, linseed;

Group II C 3 pathway: Groundnut, French bean, rice, fig, soybean, cowpea, sesame, tomato, hyacinth bean, roselle, tobacco, sunflower, grape, safflower, kenaf, castor bean, sweet potato, sweet orange, bananas, lemon, avocado pear, coconut, cotton, cassava, mango, robusta coffee, white yam, olive, greater yam, para rubber, oil palm, cocoa;

Group III C 4 pathway: Japanese barnyard millet, foxtail millet, finger millet, common millet, pearl millet, hungry rice, sorghum, maiz, sugarcane;

Group IV C 4 pathway: Japanese barnyard millet, foxtail millet, common millet, sorghum, and maize;
Group V CAM pathway: Sisal, pineapple;

III. Identification and evaluation of plant species which meets the requirements of arid and semi-arid regions for food and biomass, under and around the STPD units

The selection of proper plant species is essential to meet the requirements of the project. The main features of these crops should be:

- Drought and heat resistant
- Shadow tolerable
- Salt resistant
- Low input (Fertilizers, Chemicals and Water)
- High productivity

The plant breeding has achieved a great success in the last years in breeding of high yielding varieties and reduction of the inputs. Adapted varieties for different climatic regions produced and are also available. This is the reason why we are producing more food with less area, especially in OECD countries. The selection of the right seeds, beside water availability, is the key element for a successful farming system.
Priority should be given to introduce food and fodder crops and soil conservation. The people working in around the project sites needed to be supplied with vegetables, fruits, meat and other food to be produced locally.

The IEF can also provide an excess of energy resources in solid, liquid and gaseous states. Biomass such as wood and straw can directly used as solid energy for combustion for heat and power generation or for cooking. Oil and ethanol plants can be also cultivated for substitution for liquid fossil fuels. Wastes and other organic residues represent a suitable source to produce high quality organic fertilizers which are essential for soil improvement substitution of chemical fertilizers under and around the solar collectors.

More than 450.000 plant species exist worldwide. Only small portion of it is being used at present. For this project, several plant species Tables 6-8 have been selected to meet the requirements of the anticipated sites (4).

Table 6: Food crops to be cultivated mainly under the CSP installations

- Aubergine (*Solanum melongena L.*)
- Beans (*Vicia faba L.)*
- Chicory (*Cichorium itybus L.*)
- Cress (*Leoidium sativium L.*)
- Cucumber (*Cucmis sativus L.*)
- Herbs and spice plants
- Lady’s finger (*Hibiscus esculentus L.*)
- Melons (*Cucumis melo L.*)
- Tomato (*Lycopericon lycopersicum L.*)
- Potato (*Solanum tuberosum L.*)
- Salad (Lactuca sativa L.)
- Peppers (*Capsicum annuum L.*)
- Spinach (*Spinacia oleracea L.*)

Table 7: Freeland crops around STPD installation for the field mainly around the collectors

• Alfalfa	(*Medicago sativa L.*)
• Amaranth	(*Amaranthus ssp*.)
• Annual ryegrass	(L*olium multiflorum Lam*.)
• Barley	(*Hordeum vulgare L*.)
• Buckwheat	(*Fagopyrum esculentum Moench*)
• Groundnut	(*Arachis hypopgea*)
• Hemp	(*Cannabis sativa L*.)
• Kenaf	(Hibiscus cannabinus L.)
• Rape	(*Brassica rapsus L*.)
• Lupines	(*Lupinus ssp*.)
• Maize	(*Zea mays L. ssp. Mays*)
• Meadow foxtail	(*Alopecurus pratensis L*.)
• Quinoa	(*Chenopodium quinoa Willd*).
• Reed canary grass	(*Phalaris arundinaceae*)
• Rosin weed	(*Silphium perfolatium L*)
• Safflower	(*Carthamus tinctorius L*.)
• Salicornia	(*Salicornia bigelovvi Torr*.)
• Sesame	(*Sesamum indicum L*)
• Soybean	(*Glycine max (L.) Merr*.)
• Sugar cane	(*Saccharum officinarum L*.) *
• Sunflower	(*Helianthus annus L*.)
• Sweet sorghum	(*Sorghum bicolor L. Moench*)
• Switch grass	(*Panicum virgatum L*.)
• Tall fescue	(*Festuca arundinaceae Schreb*.)
• Timothy	(*Phleum pratense L*.)
• Topinambur	(*Helianthus tuberosus L*.) *
• Triticale	(*Triticosecal*e)
• Oats	(*Avena sativa L*.)
• Rye	(*Secale cereale L*.)
• Wheat	(*Triticum aestivum L*.)

* = perennial crops (all others are annual)

Table 8: Trees, Tall grasses and agro forestry for STPD fields

• Argan tree	(*Argania spinosa*)*
• Bamboo	(*Bambusoideae*) *
•Black locust	(*Robinia pseudoacacia L*)*
• Broom (Ginestra)	(*Spartium junceum*)*
• Cardoon	(*Cynara cardunculus L*.)*
•Gigant knotwees	(*Polygunum sachalinensis F. Schmidt*)*
• Common reed	(*Phragmites communis Trin*.)*
•Cordgrass	(*Spartina ssp*.)*
• Date palm	(*Phoenix dactylifera*)*

• Eucalyptus (*Eucalyptus spp*.)*
• Fig-tree (*Ficus caraca L.*)
• Giant reed (*Arundo donax*)*
• Jojoba (*Simmondsia chinensis*)*
• Miscanthus (*Miscanthus ssp*.) *
• Olive (*Olea europaea*.)*
• Pomegrante (*Punica granatum L.*)
• Perennial ryegrass (*Lolium perenne L.*) *
• Poplar (*Populus spp*.)*
• Sesbania (*Sesbania spp*.)*

IV. Cultivation procedures

Special attention should be paid for the crop management which has to allow an efficient of the water. The combination of several measures is essential for water and soil conservation and optimum plant growth:

- Soil preparation
- Water supply
- Plant protection
- Crop management and crop rotation
- Harvesting, storage and conservation
- Ecological farming
- Desert cultivation system

V. Identification of water efficient irrigation systems

The identification and application of water saving irrigation technologies is one of the most effective measures to reduce the water required water rates for a proper plant growth. The technologies of irrigation are in the process of continues improvement and the water supply could be considerably reduced. Following advanced systems have to be considered in the project:

- Drip irrigation
- Micro sprinklers
- Advanced spray irrigation technologies (Centre Pivots)

Careful selection of the right systems for various applications; under the solar collectors, around the solar collectors and in the greenhouses has to considered.

VI. Waste water management

Human activities within of the project produce and also animal husbandry produce considerable amounts of waste water which should be treated and recycled. The reuse of waste waters needs adequate treatment before its re-injection in the irrigation system.

-Micro filter systems for solid separation
-Solid densification > low volume and transportation
-Field irrigation of fluid residues (organic fertilizer)

VII. CSP multi-purpose-plant: Technical assumption

The STPD is designed as a multi-purpose-plant, providing desalinated water and electrical energy for domestic and industrial demand. Plants like calculated in Tab. 9 will have a total Solar Field size of 8, 5 ha (9).

Tab. 9: Technical and economic parameters CSP

Investment			Cost			Technology		
MED-Plant	5,8	M$	Capital	2,14	M$/y	Power	5	MW
Solar Field	20,0	M$	O&M	0,91	M$/y	Water	5000	m^3/d
Storage	5,5	M$	Insurance	0,18	M$/y	Solar Share	0,75	
Power Block	5,3	M$	Fuel	0,64	M$/y	Fuel Share	0,25	
Total	**36,5**	**M$**	**Total Cost**	**3,87**	**M$/y**	Gross Efficiency	0,33	
Required Support	17,0	M$	Revenue Water	-1,50	M$/y	Full Load Hours	8000	h/y
Eff. Investment	***19,5***	***M$***	***Effective Cost***	***2,37***	***M$/y***	Net Electricity	40,0	GWh/y
			Effective LEC	***0,059***	***$/kWh***	Water	1,7	Mm^3/y
						Solar Field Size	84000	m^2
Spec. Inv. MED	1150	$/$m^3$/d	Debt Period	20	y	Available Heat	91,3	GWht/y
Spec. Inv. SF	238	$/$m^2$	Interest	9,0%		Spec. Heat MED	54,8	kWh/m^3
Spec. Inv. PB	1050	$/kW	O&M Rate	2,5	%/y	Spec Elec. MED	2	kWh/m^3
Spec. Inv. Sto.	73	$/kWhe	Insurance Rate	0,5	%/y	Total Elec. MED	3,3	GWh/y
Fuel escalation	1,20%		Fuel Price	17,5	$/MWh	Storage Capacity	15	h
Plant Life	40	y	Water Price	0,9	$/$m^3$	Storage Capacity	75	MWh

The required land area of this CSP will be twice or three times the size covered by the solar field , depending on the spacing between the solar thermal collectors, so a total area of approximately 17 -25 ha can be used for additional activities. Depending on the stand width and installed solar thermal system, different areas will be partially shaded. Partially shaded areas in arid or semi-arid regions will lead to a decrease in the yearly medium temperature, a strong impact to the microclimate compared to the surrounded environment (which might be mostly dessert). Additionally irrigation with about 10 % of the desalinated water, which will be about 170.000 m^3 per year, will support rural development. Surrounded tree plantations and free land crops and grasses will increase the total required land area to some 50 ha and (circumstance) have further impact on the development of fertile soils. This will provide a proper area with moderate micro-climate for various agriculture and social as well as pleasant living conditions, which are additional aspects for the multi-purpose of the Solar Thermal Power and Desalination Units.

A technical layout of a multi-purpose concentrating solar power plant generating electricity and water desalination for the industrial and agricultural development of desert or semi-desert zones is given in Fig.4**.**

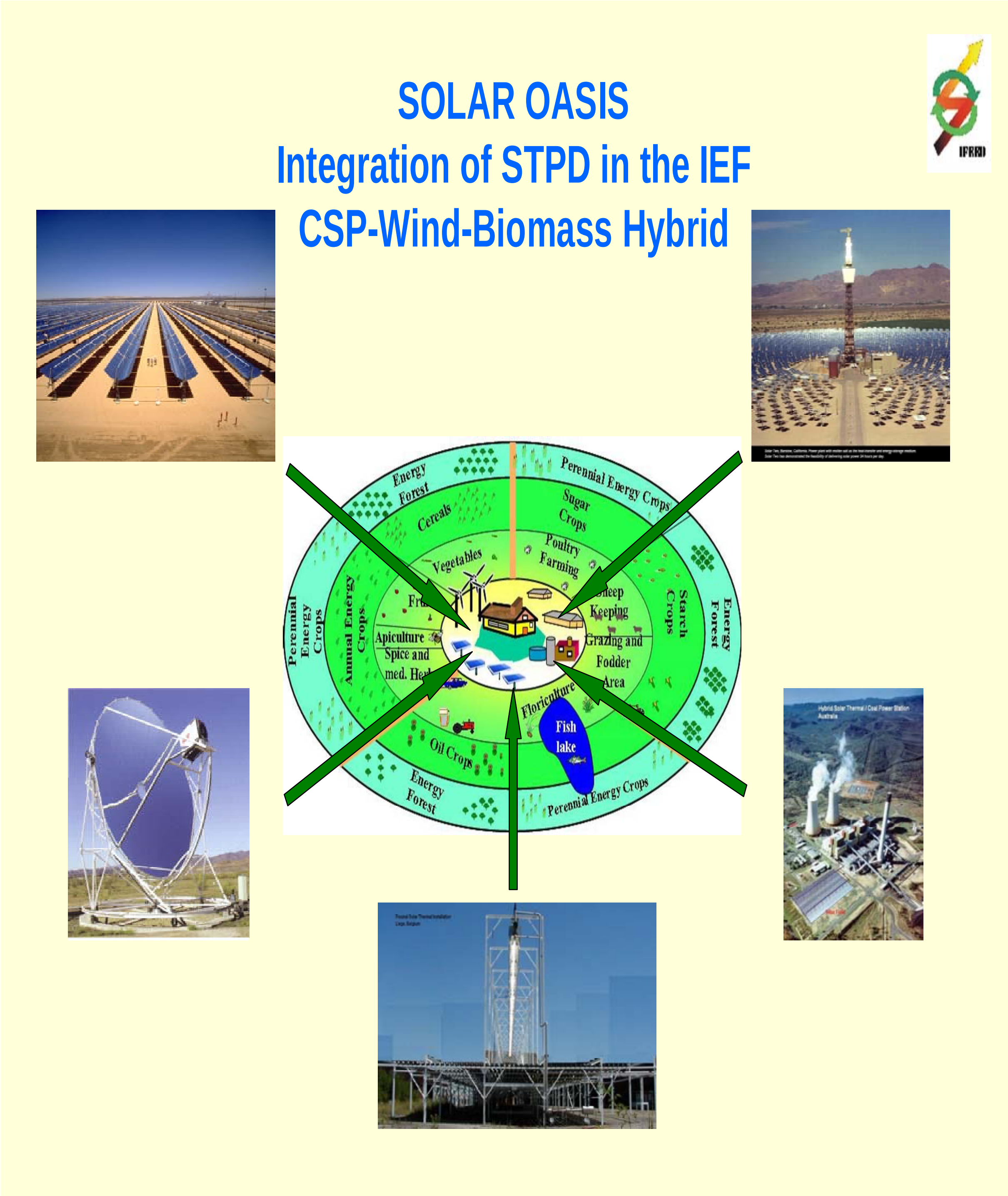


Figure 4: Integration of various CSP systems in the IEF

These main features of agricultural activities extend the design of the STPD as a multi-purpose-plant, providing sustainable water, food and energy for regional demand as well electricity export. Furthermore herbs, medical crops as and raw materials for various industrial uses can be provided by such farm side to close the cycle of a real sustainable multi-purpose-plant. The combination of food, water and energy production in rural areas has been worked out by the FAO working group 3 (Biomass for Energy and Environment, SREN) and described as Integrated Energy Farm.
Farming systems under and around the STPD is exactly in conformity with the concept of the Integrated Energy Farm, although social and ecological factors are involved. In case of on-site production of seeds and organic fertilisers by implementation of medium scale biogas plants, the input factors of a STPD as an IEF are minimised to salt water, solar energy and fuel for agriculture machines, which also might be produced onsite (plant oil, ethanol, and biogas). This guarantees a sustainable, fossil fuel independent maintenance of the IEF and will trigger the economic development of arid regions as well as combat desertification.

In case of food production beneath an assumed CSP solar collector field of 8,5 ha size and an irrigation rate of 1 $m^3/m^2/a$, which is 10% of the units output, a total area of 17 ha will be provided for different types of horticulture, for example greenhouse culture or free land farming. Farming techniques under the solar fields have to be adapted to the technical construction of the solar field, i.e. the stand width and height of the solar collector field. Suitable sprinkler or drip irrigation systems have also to be evaluated.
Direct food crop production for human nourishment will be the first choice, as animal husbandry on 17 ha might only be sufficient for ca. 50 cows for example and the efficiency rate kg (or MJ) food / m^2 might be the lowest under relatively cool, shady and fertile soil.

VIII. Greenhouse facilities

Greenhouse facilities offer the good options to produce vegetables and decrease the water use rates. Anyhow, cooling devices might be necessary under hot climates.
The most suitable glass or plastic type of greenhouse facility has to be evaluated for the construction under the STPD. Both types will lower the evaporation of water and increase the efficiency of irrigation. In this case of partially shaded areas under the solar field nightshade plants and half shadow resistant plants have to be evaluated. A controlled water supply under and around as well as in greenhouse facilities provide a moderate climate to a large number of food crops and allow a crop rotation for at least twice a year is possible.

Considering all above mentioned aspects, the IEF could be implemented by careful selection of plant species for their cultivation under and around the solar collectors. Shadow tolerable plants with especially vegetative characteristics, with a usable harvest index (HI) higher than 90%, have priority to be cultivated under the collectors, as thy have the highest water use efficiency rate.
Crops to be cultivated around the collectors could be a mixture plant with vegetative and productive parts. A selection of various plant species has been given in tables 6-8 and a preliminary distribution of these crops has been incorporated in fig. 5.

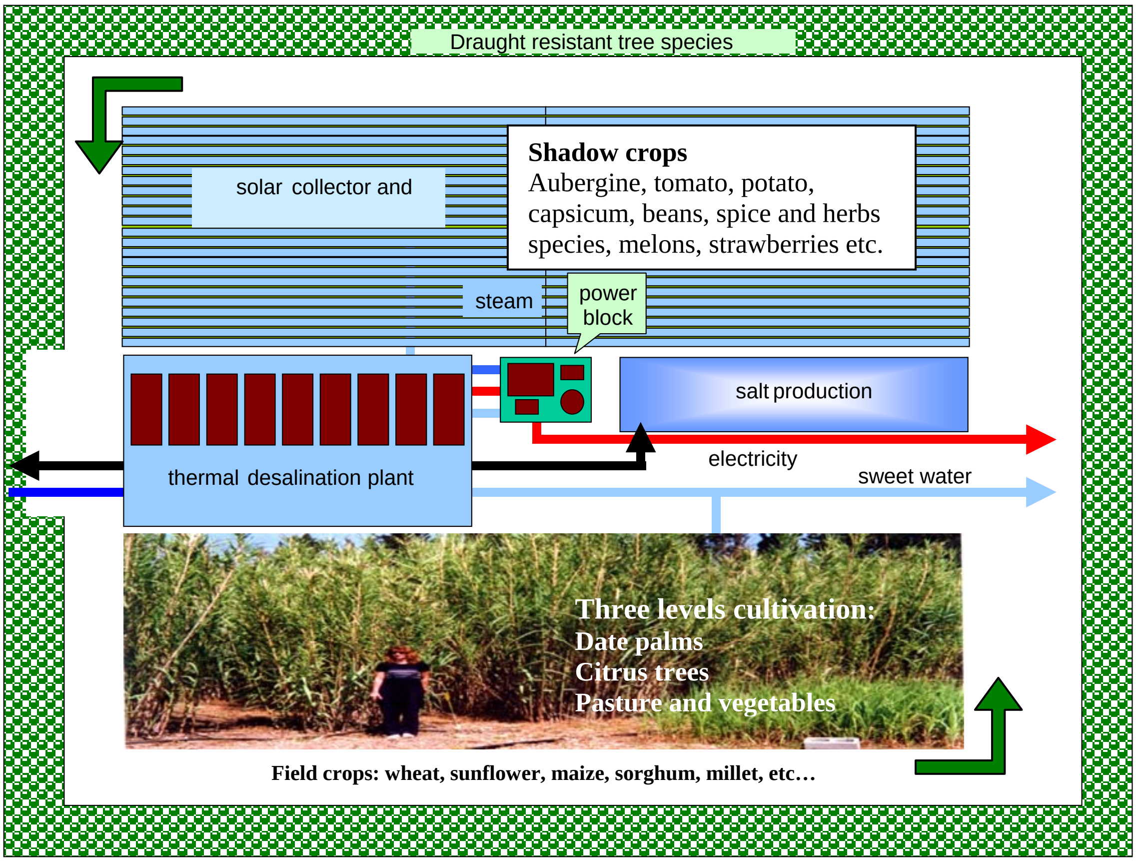


Figure 5: Cultivation systems under and around the Multi-Purpose Concentrating Solar Power Plant

IX. Impact on climate, environment and desertification

The implementation of the IEF in the CSP project has several positives effects on the soils, climate and the environment:

-improving soil conservation
-increasing soil fertility
-water conservation
-creating of a favourable micro climate
-protection of the STPD Installations from sand and dust
-combating desertification

X. Social and economic impact

The concept includes social and economic elements which are of a great importance for the population in remote and areas:

- Job creation for farmers and technicians of different disciplines in farming, irrigation, landscape, animal husbandry, food conservation etc.
- The project opens chances for the young people to be trained and improving their skills.
- It will attract different groups from various disciplines and tourists.
- The processing and conservation of food could have positive economic effects.
- The production of solid fuels from biomass represents additional economic revenue.

Conclusions

It can be concluded that the adaptation of the FAO Concept "Integrated Energy Farm" (IEF) could offer the possibilities to reduce the water requirements for irrigation through selection of draught and heat resistant adapted crops, using water saving irrigation technologies and introduction of combination between desert cultivation appraches, greenhouse facilities and ecological farming systems.

The planning of the IEF consists of 4 pathways: Food, energy, environmental and social-economic pathways. The outputs are, beside the power, heat and water, food, fodder, education, training and employment. Soil conservation, microclimate improvement are further positive effects on sustainable development of the site.

Several plant species have been identified to be cultivated under and around CSP installations. They include herbal crops, vegetables, grasses, grains, pulses, shrubs and trees. Emphasis will be put on drought tolerant, salt resistant and high productive genotypes with a harvest index (HI) higher than 50%.

The area which can be cultivated with the desalinated water ranges between 17 and 50 ha annually, depending on HI.

Agricultural activities are almost subsidised (OCED countries 1 billion dollars every day). Considering the global market, it could be estimated that the prices of the agricultural products produced under and around CSP stations could range between 0.12 and 1.20 Dollars per kilogram of food.

All these assumption has to be verified in a demonstration project.

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