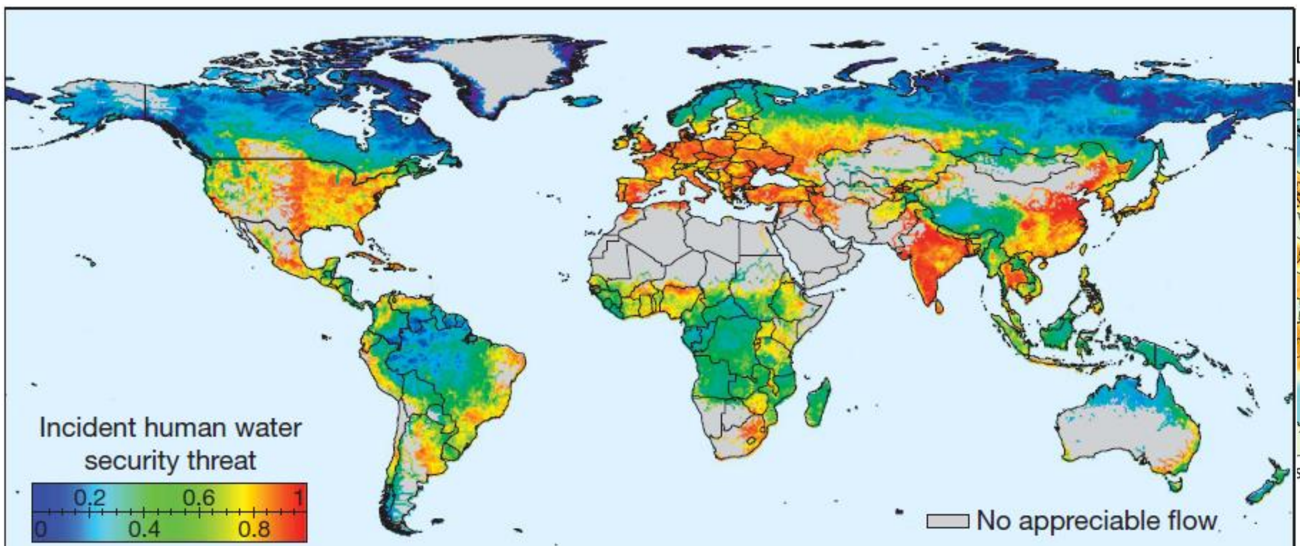
Solar Energy Desalination: Co-generation of water and electricity

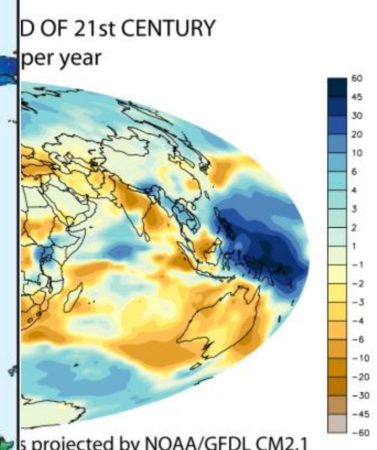
Costas N. Papanicolas

The Cyprus Institute

Global Fresh Water Stress

- Cyprus, like many other islands in the Mediterranean and MENA region in general are stressed for water. Tourism exacerbates the problem.
- Climate change impacts
  - Reduction of precipitation in already stressed regions

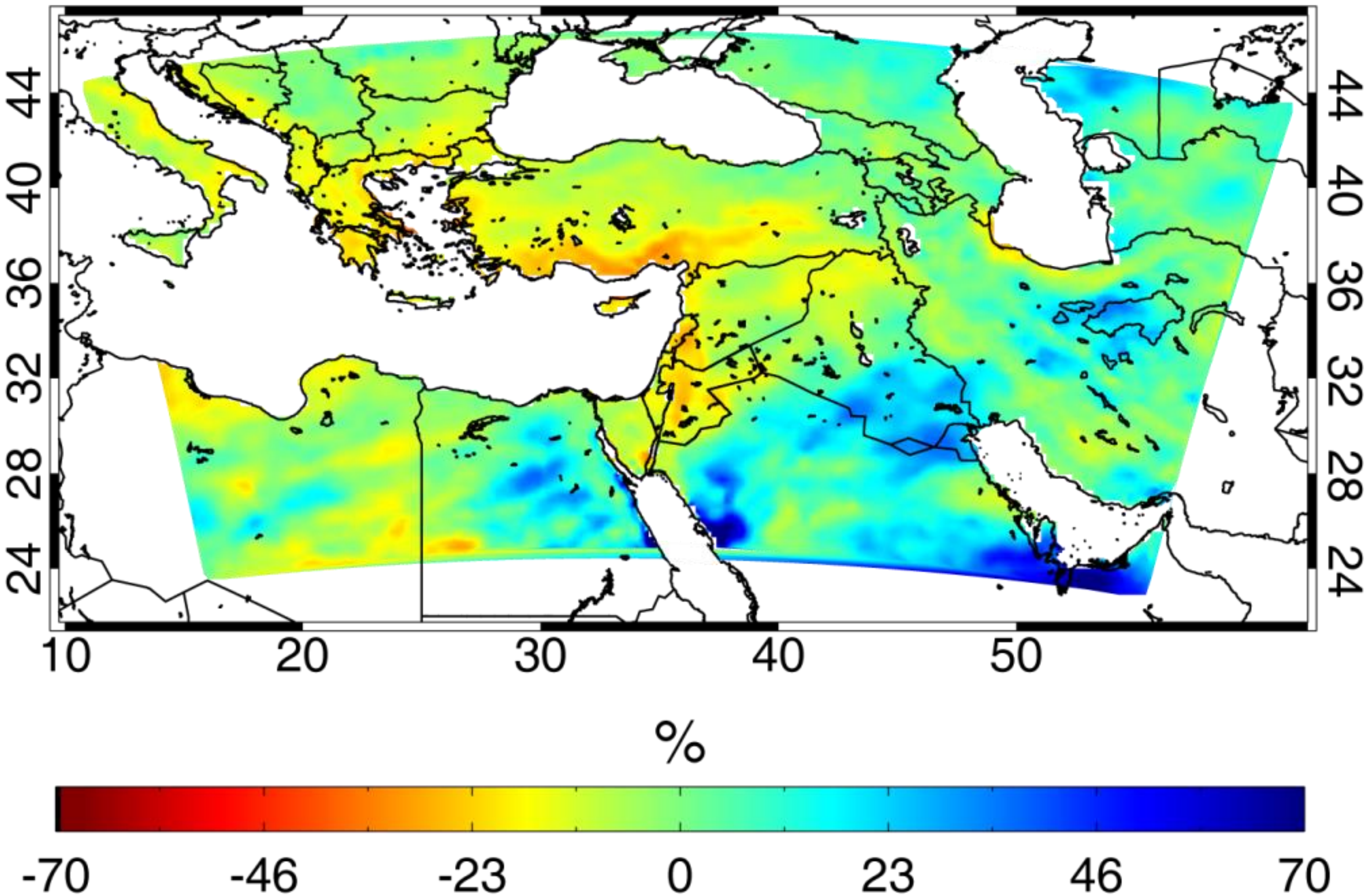




Source: Vorosmarty et al, "Global threats to human water security and river biodiversity", Nature, **467**, pp. 555-561, 2010 and NOAA

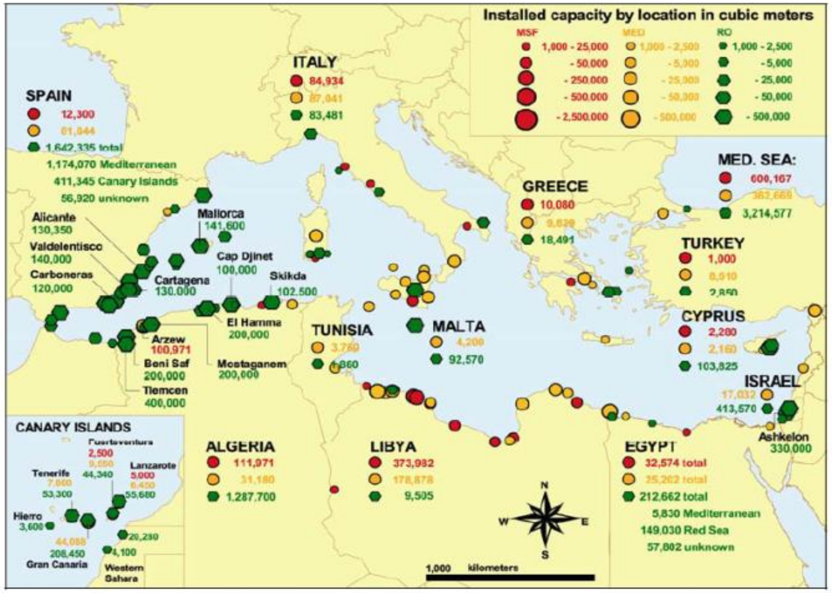
Climate Change and precipitation

CyI Modeling: Model change in annual precipitation between 1961-1990 and 2040-2069



Desalination option

- Islands are surrounded by water (97.5% of the global water resources are in saltwater)
- Globally ~16 000 desalination plants in operation or under construction



- Turn to desalination
  - Energy intensive process
  - Typically driven by fossil fuels
  - Adverse climate impacts

Case of Cyprus

Cyprus uses more than 4% of total electircity consumption for desalination.

Source: Lattemann and Hopner, Desalination, 220, pp. 1-15, 2008

Water & Energy Nexus

- **Water and electricity demand is on the increase**
- **Water supply will diminish**
- **Desalination is on a steep rising path – however very energy hungry (4.2 kWh/ 1 m^3 water)**
- **Green house gas emissions increase, further exacerbating the problem.**

Proposed Solution: Cogeneration of Desalinated Sea Water & electricity using Concentrated Solar Power

- **Feasible**
- **Well suited to Coastal and island enviroments**

CSP-DSW Technoeconomic Study

Study Scope: Techno-economic assessment for Solar Thermal (CSP) co-production of electricity and desalinated water

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The Cyprus Institute, CSP-DSW Study, 2011, C.N. Papanicolas Ed.

Desalination options

- Mature desalination technologies
  - Main technologies are MSF/MED and RO. Issues of scale!

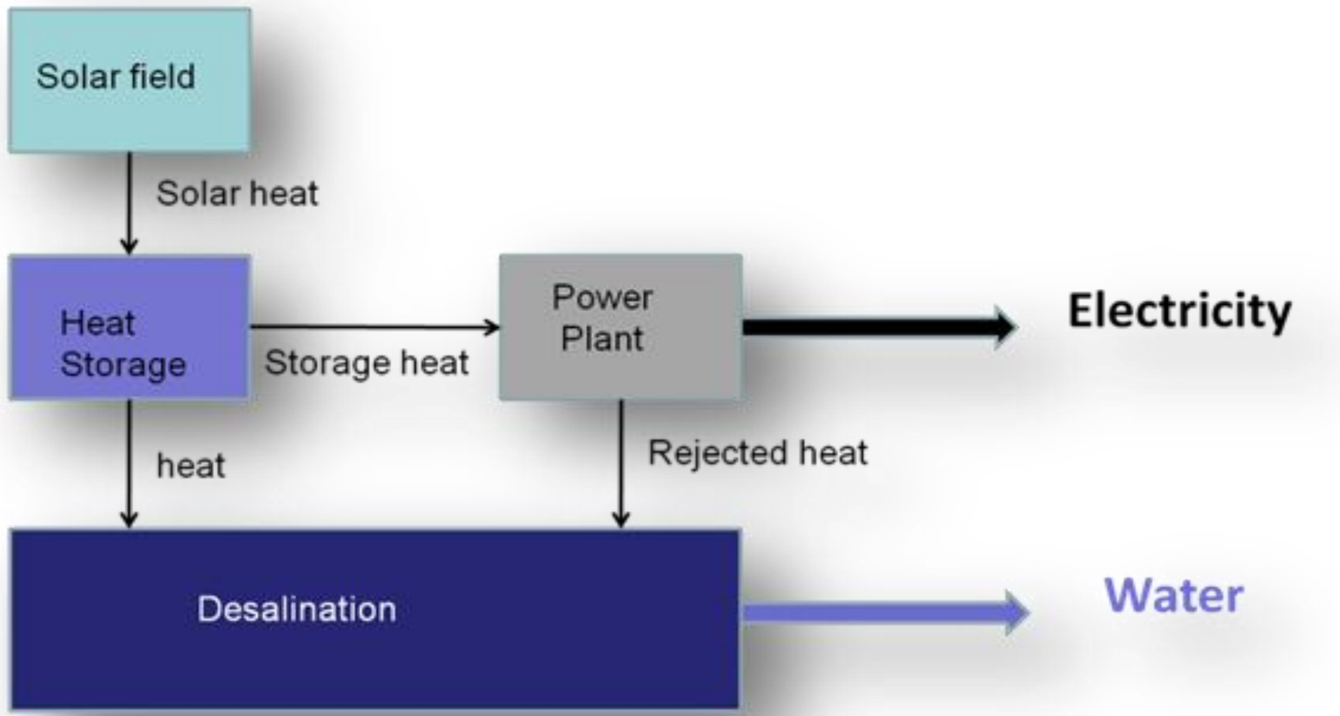
Separation	Energy Use	Process	Desalination Method
Water from Salts	Thermal	Evaporation	Multi-Stage Flash (MSF)
			Multi-Effect Distillation(MED)
			Thermal Vapour Compression (TVC)
			Solar Distillation (SD)*
		Crystallisation	Freezing (FR)
			Gas Hydrate Processes (GH)
		Filtration/Evaporation	Membrane Distillation (MD)
	Mechanical	Evaporation	Mechanical Vapour Compression (MVC)
		Filtration	Reverse Osmosis (RO)
Salts from water	Electrical	Selective Filtration	Electrodialysis (ED)
	Chemical	Exchange	Ion Exchange (IE)


Typical thermal desalination plant


Typical RO desalination plant

Source: AQUA-CSP Study, DLR

CSP-DSW Co-generation concept



The advantages of CSP-DSW are realized only when the power and desalination cycles are integrated thermally and optimized together.

Concentrated Solar Power (CSP)

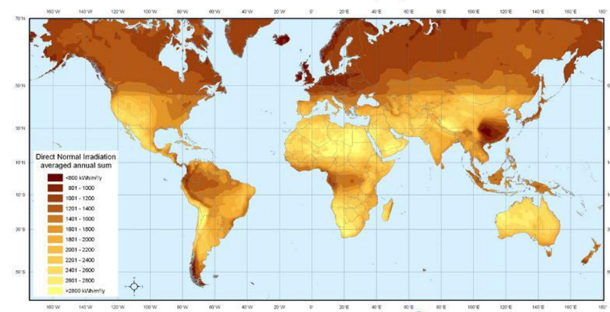
- Reflectors concentrate the rays of the sun onto a heat collecting element
- Heat is then used to make steam and using a turbine produces electricity

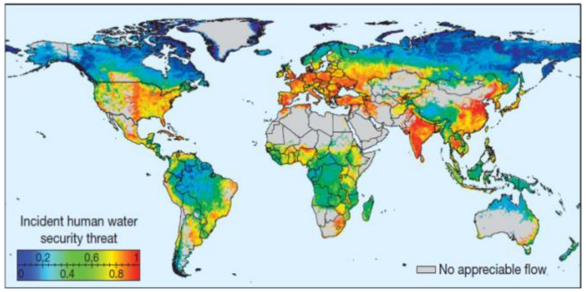
Concentrated Solar Power (CSP) + Desalination

- Advantages in combining CSP with Desalination
  - Locations with water stress typically also have high solar potential
  - There is technological synergies in combined production of electricity and desalinated water vs. independent production of the two products
  - Financial benefits as water and power pricing options can be tailored to specific location
  - Storing Desalinated Water is a form of Energy Storage
- Drawbacks
  - Proximity to coastline required

Technical aspects still need to be addressed for coastal plants.

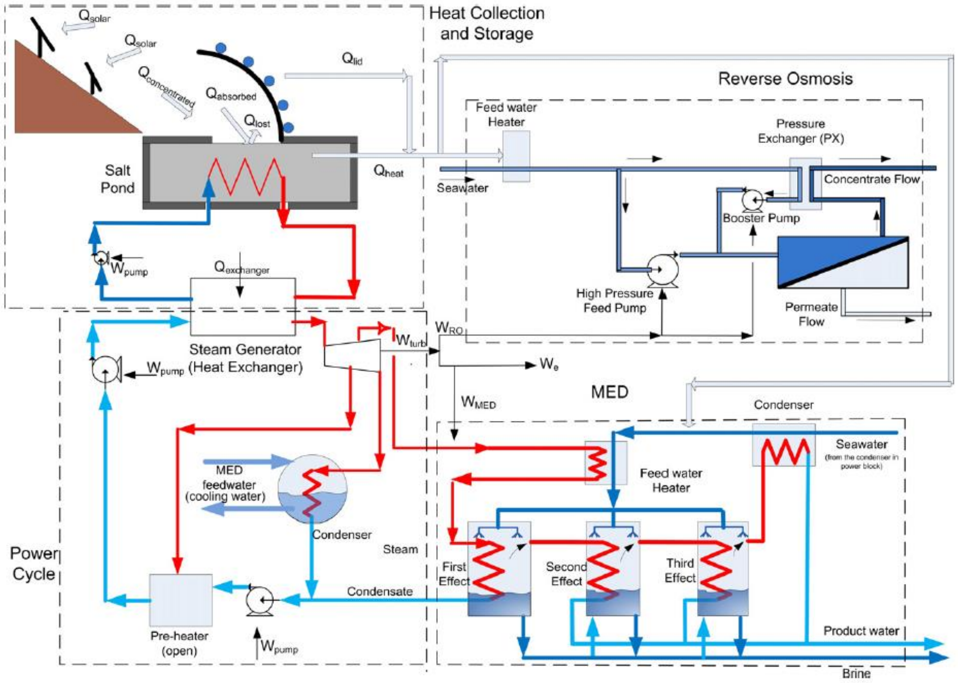
Direct Normal Irradiation (DNI)





CSP + desalination

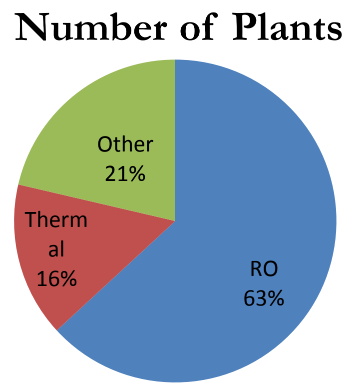
- Co-generation scheme
  - Integrated thermodynamic cycle
  - Joint optimization of power and desalination subsystems
  - Utilization of harvested heat

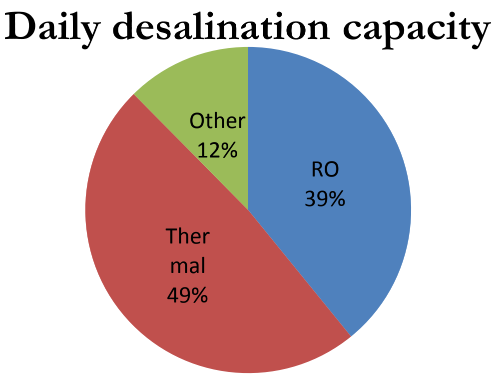


Source: Ghobeity et al. Solar Energy 85, pp. 2295-2320, 2011
& The Cyprus Institute, CSP-DSW Study, 2011, C.N. Papanicolas Ed.

Potential Markets

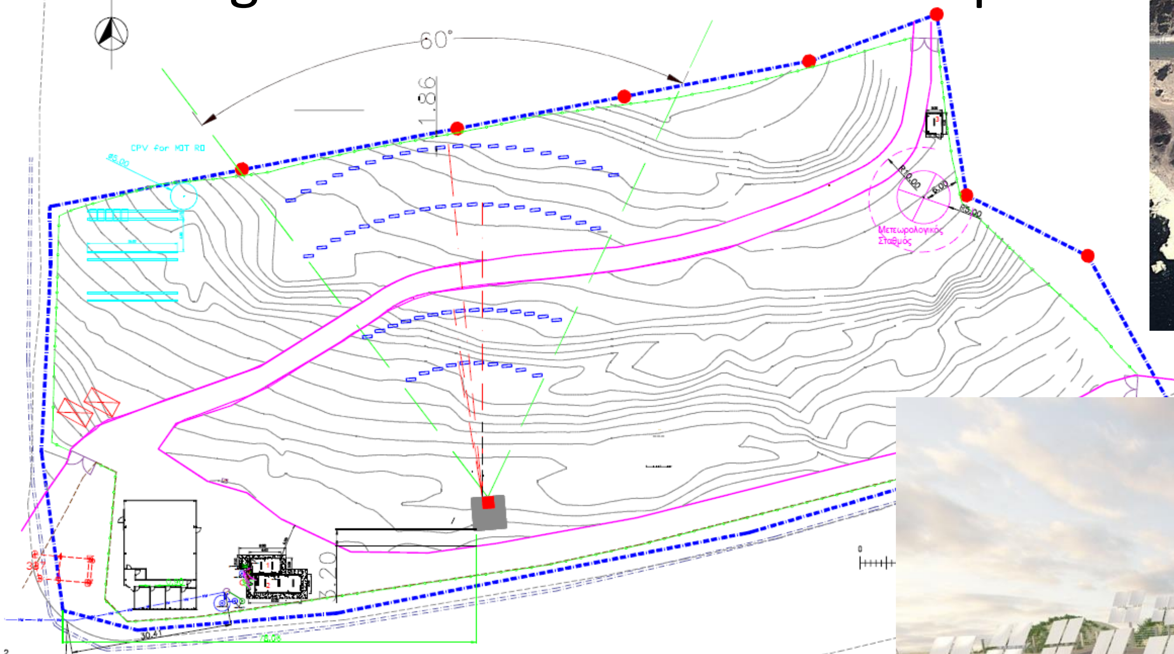
- Depends on plant scale
  - Large plant: km^3/day
    - Cities, countries
  - Small plants: few m^3/day
    - Individuals
    - Isolated communities/islands
    - Large Hotel Complexes
    - Niche market for CSP+D

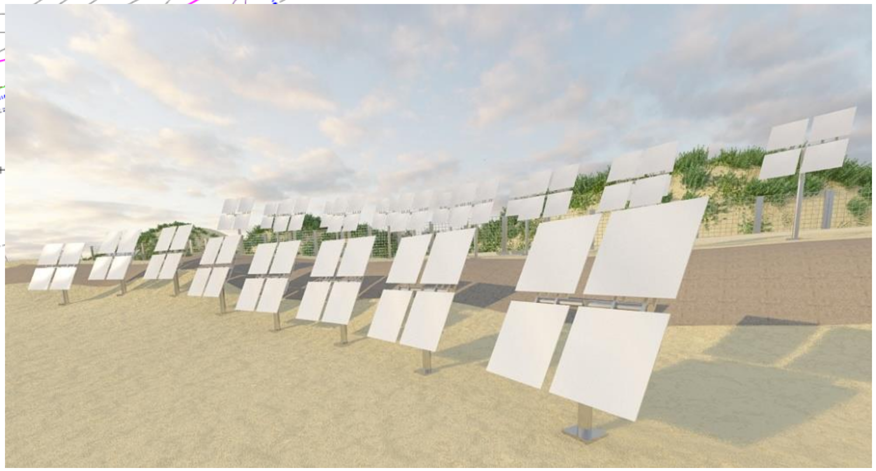




Cyprus Institute Research

Design, Construct and Test a cogeneration Experiment (mini plant) to test the technological soundness of the concept





Currently under construction. Will be commissioned early next year.

Financial Analysis

Financial Analysis Results (4MW)

Without GHG benefits

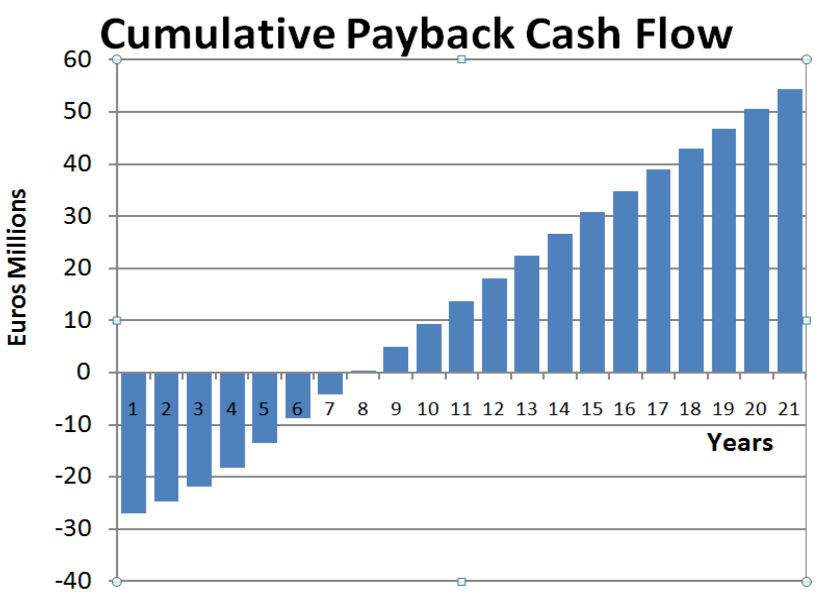
NPV: **19.1 Million Euros**

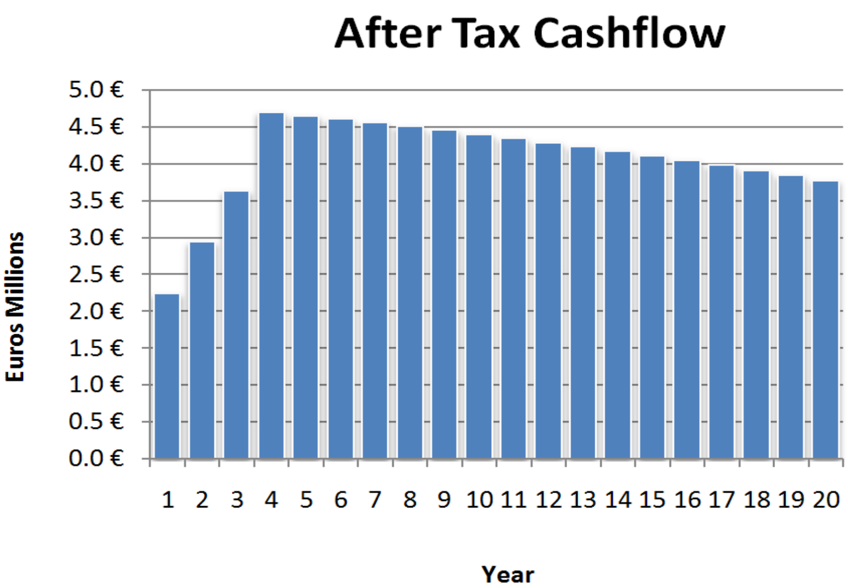
IRR: **13.26%**

Benefit cost ratio: **0.706**

Revenue cost ratio: **3.19**

Simple non-discounted payback: **7.9 yrs**





With GHG benefits the financial performance is further enhanced!

Technoeconomic Study:

TWO INTERESTING POINS:

1. Desalination of sea water from being an expensive necessity, and drain on the power grid (currently ~ 4% of electricity consumption in Cyprus) becomes an energy storage medium, lowering the overall cost of electricity.

2. The FIT for Electricity distorts the picture: water production is penalised hence the low LCOE for maximum electricity production and large LCOW for the first case.

NEED APPROPRIATE TARRIF STRUCTUTRE FOR **BOTH** ELECTRICITY AND DESALINATED WATER

Conclusions

- Islands in water stressed regions (e. g. Cyprus) often have high solar potential
  - Drive desalination with solar power

- Cogeneration of Electricity and Desalinated Sea Water – most promising:
  - Only water production
  - Water + Electricity production
  - Gains in efficiency in a co-generation plant

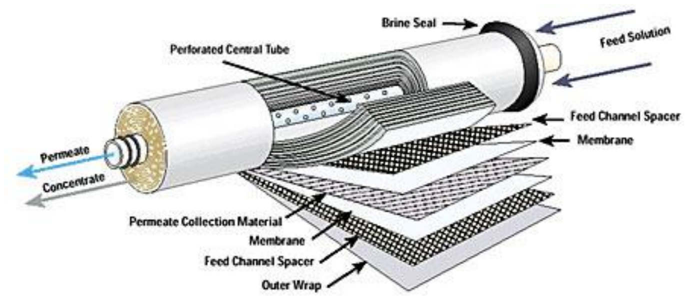
- Research and demonstration plants are under construction. Expect commercialization in the next five years.

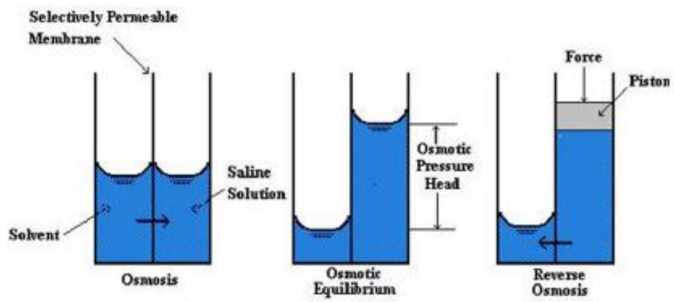
Thank you for Your Attention!!

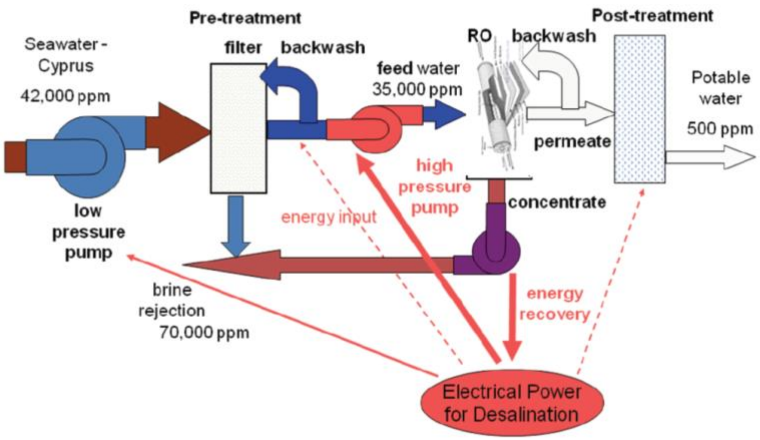
energy@cyi.ac.cy
Solar Energy and Desalination Group
Energy Environment and Water Research Center
The Cyprus Institute

Reverse Osmosis (RO)

- Reverse Osmosis main components
  - Separation membrane
  - High pressure pump
  - Pre- and post-treatment
- Energy requirements
  - Electrical requirements
  - 3-4 kWh/m^3



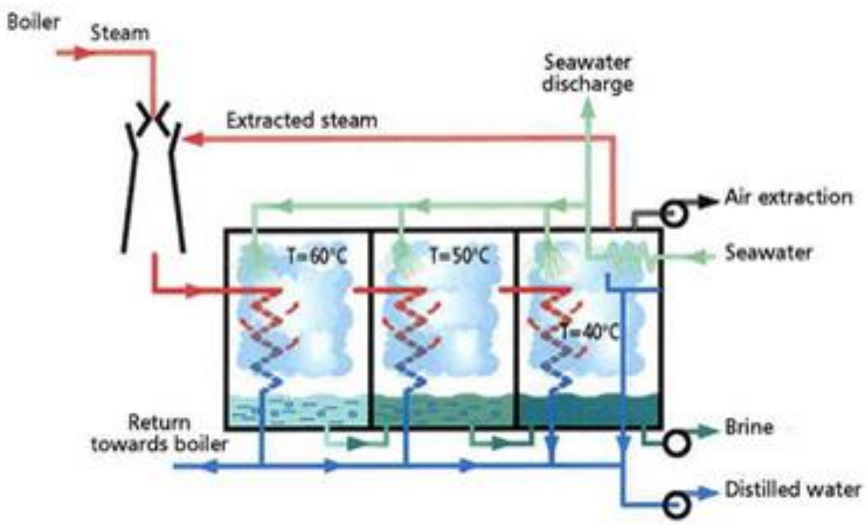




Source: ABB, www.filterwater.com

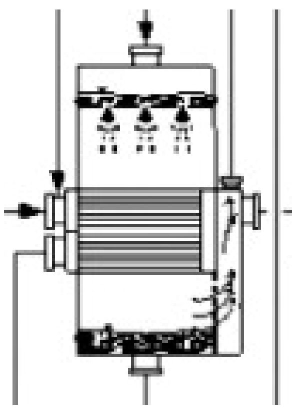
Thermal desalination

- Thermal desalination technologies include
  - Multi-Stage Flash (MSF)
  - **Multi-Effect Distillation (MED)**
  - Thermal Vapor Compressor (MED-TVC)



Multi Effect Distilation (MED) operation

- Recent advances
  - Plate heat exchangers
  - Large heat transfer area / compact design
- Ease of operation compared to RO
  - Most complicated component is a pump
  - No specialized service personnel required
  - Allows intermittent operation



Shell & Tube type MED

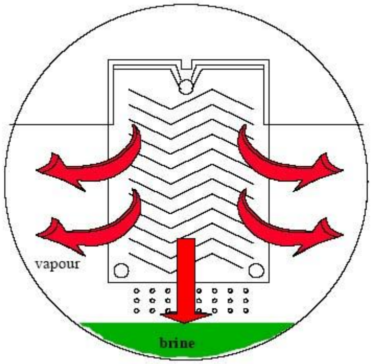


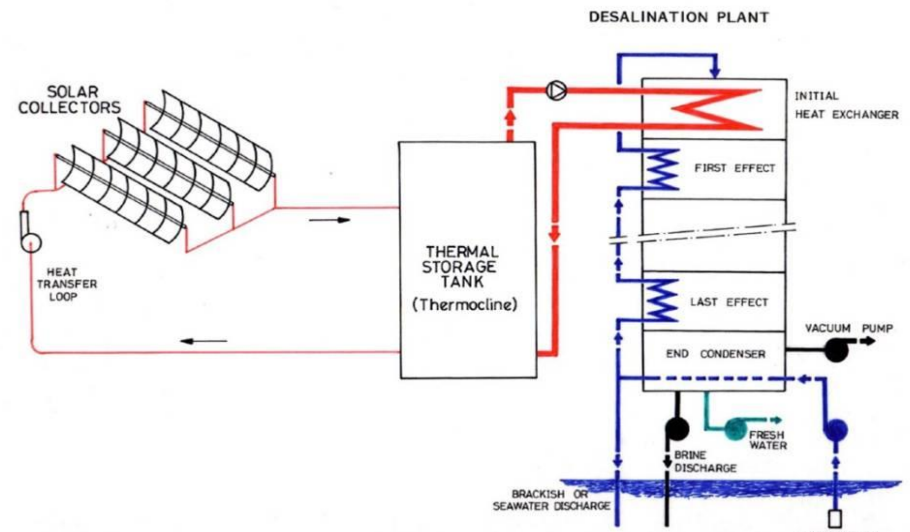
Plate heat exchanger type MED

MED characteristics

- Requires low temperatures < 80 °C
  - Higher than 80 °C promotes scaling/fouling
- Power requirements
  - Thermal requirements
    - ~60 kWh_{th}/m^3
  - Electricity requirements
    - 1-1.5 kWh_e/m^3
- Performance definition
  - Gain Output Ratio
  - GOR = <distillate mass> / <steam mass>
- Performance scales with number of effects
  - Typically up to 20 effects with GOR of 12-15

CSP + Desalination

- Stand-alone solar desalination
- Main components:
  - Solar field (concentrating or non-concentrating solar thermal collectors)
  - Thermal storage MED unit
  - Pumps
    - Seawater
    - Vacuum
    - Brine discharge



Source: Plataforma Solar de Almería, Spain

Financial Analysis

Assumptions and Considerations

Income and Performance

Electricity selling price to grid: 0.26 €/kWh (Cyprus FIT for CSP)

Water selling price: 0.92 €/m^3 (no FIT exists for "green" water)

Capacity factor: 85% (50,60 and 70% for first 3 years)

Clean Development Mechanism (CDM) benefits

GHG emission factor: 0.8 Ton/MWh

Benefit: 14 Euros per Ton of CO_2

Financial Analysis

CSP-DSW System Parameters (nominal 4MW facility)

OTHER COSTS
Utilities: 1.5 Million Euros
Site works: 1.5 Million Euros
Piping: 1.5 Million Euros
Salt: 0.46 Million Euros

Personnel Costs per year
Salaries: 670 k Euros
(30 people, technicians and administrators)

Land Requirements
Required land area: 214,000 m^2
Land cost: 2.1 million Euros

For further studies the price of land needs to be more precisely defined, here the figure assumed is quite low and corresponds to high-inclination land

Annual Production
Electricity Production: 25.7 GWh
Water Production: 310,870 m^3

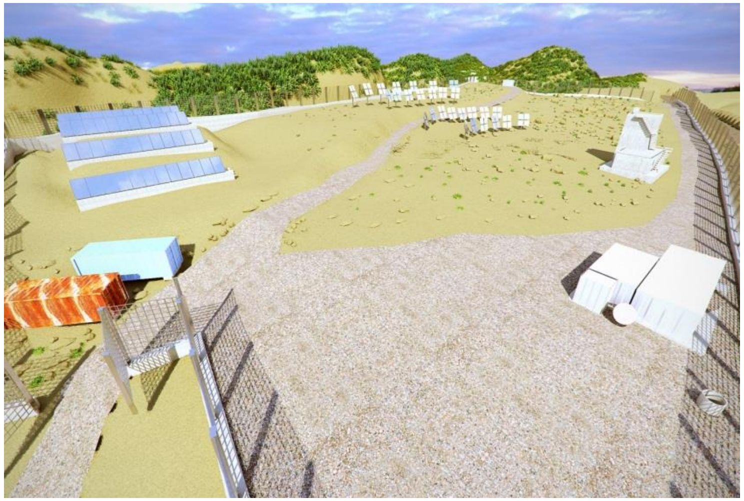
This system employs a very small MED unit for water production. This is to maximize profit since the FIT for electricity favours its production over water

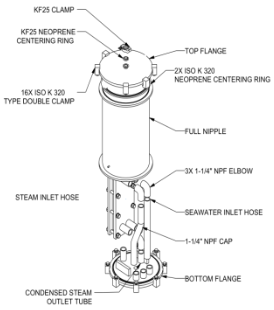
Challenges

- Modeling steady and dynamic desalination processes
  - Robust technologies under variable operation rate
- Effective integration with CSP plant for water + power production
  - Development and analysis of energy backup concepts and hybrid plants
  - Heat extraction possibilities in a CSP plant
- Performance assessment of CSP+D plant
- Appropriate storage technology for continuous operation

Cyprus Institute Research

- Development of a small scale 4-effect MED unit
  - Determine performance ratio for variable heat input
  - Develop modeling tools to predict performance
  - Integration with CSP plant
- Testing in realistic coastal environment





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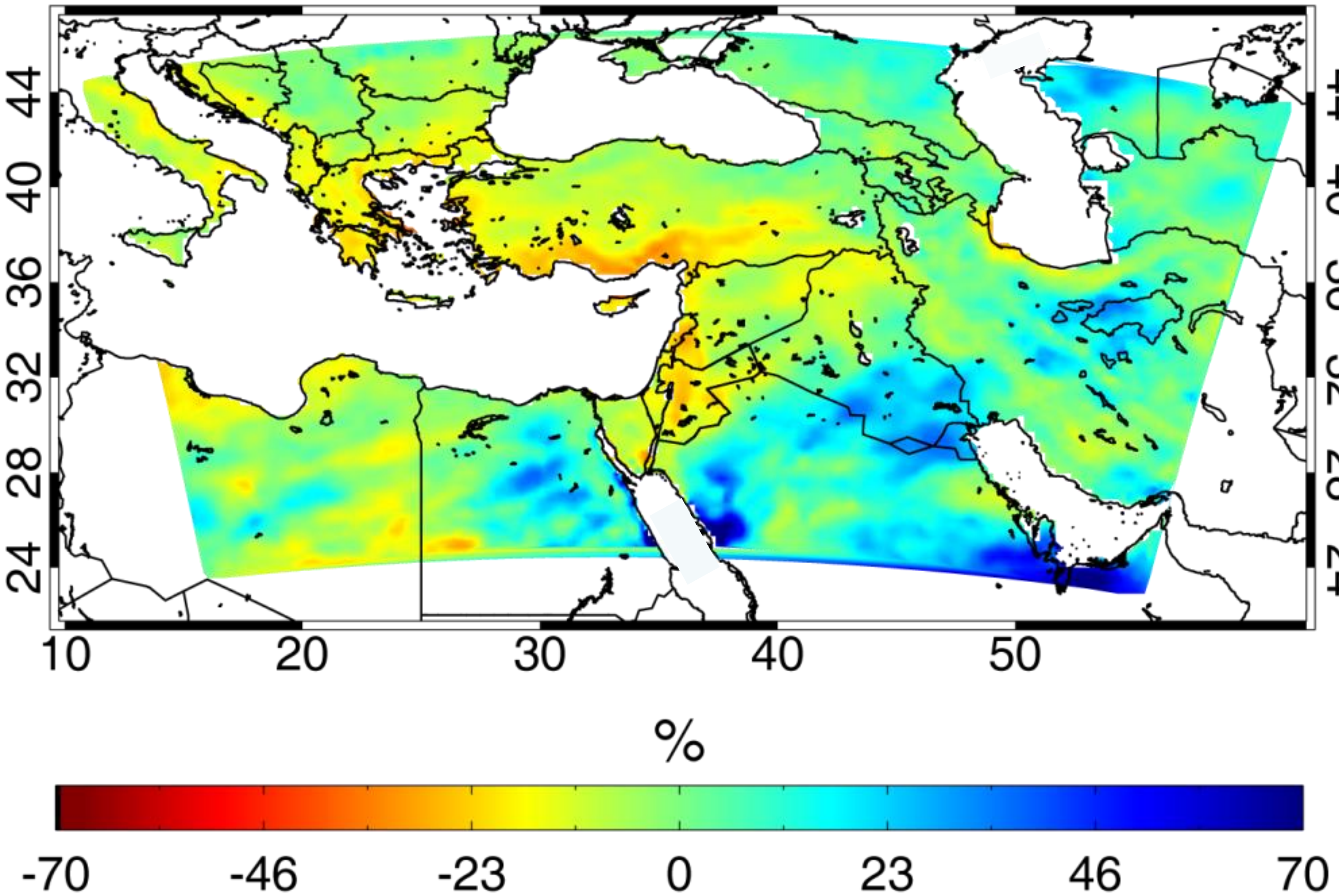

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The Climate – Water – Energy nexus
(& how to decarbonize it)

At the Mediterranean the issues of climate, energy and water are interwoven:

- **Economic and population Growth – requires more energy**
- **and water (increasing desalination – more energy)**
- **Lead to increase in emissions.. which exacerbate the problem**

Addressing the issues of climate, energy and water:

- Lower **demand** for Energy (& stimulate the economy)
- **Supply** w. renewables (solar!) – (and cogenerate water)
- Create economic growth & social cohesion through job creation in these factivities