Desalination based on micro gas turbines

Flexible, robust, economical… better?

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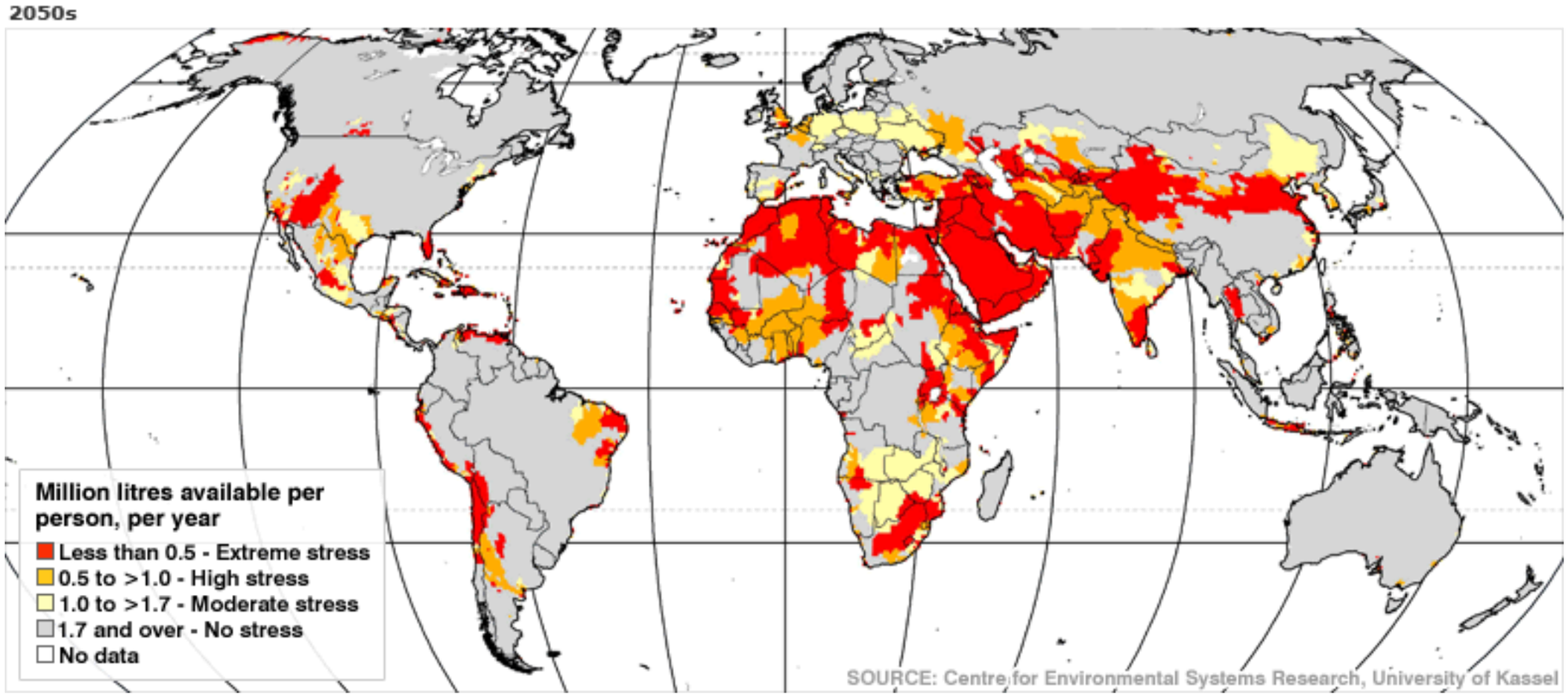
CIEMAT
Spain

[3]Abengoa
Technology Incubator
Spain

0. Contents

1. Overview of water needs



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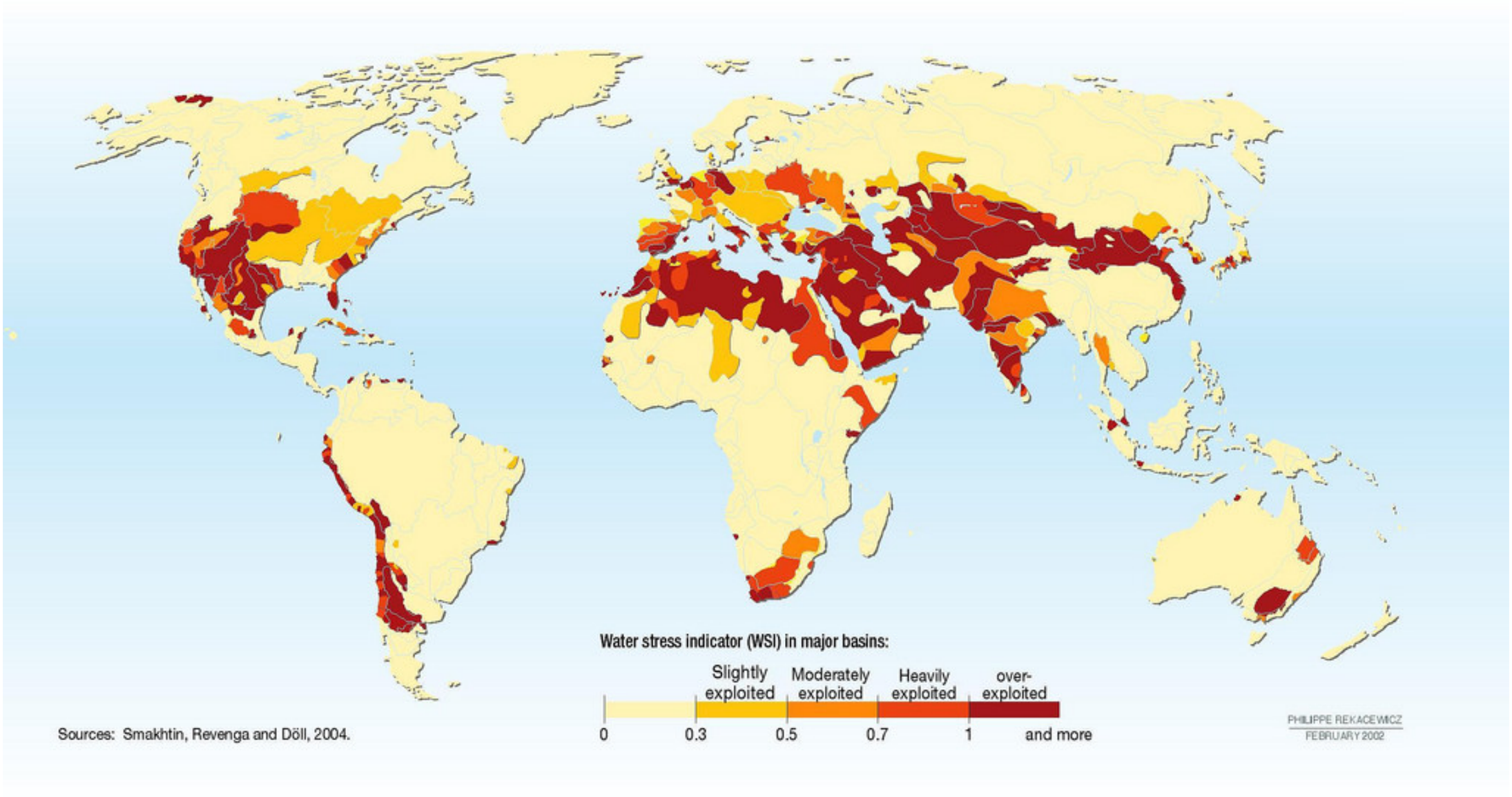

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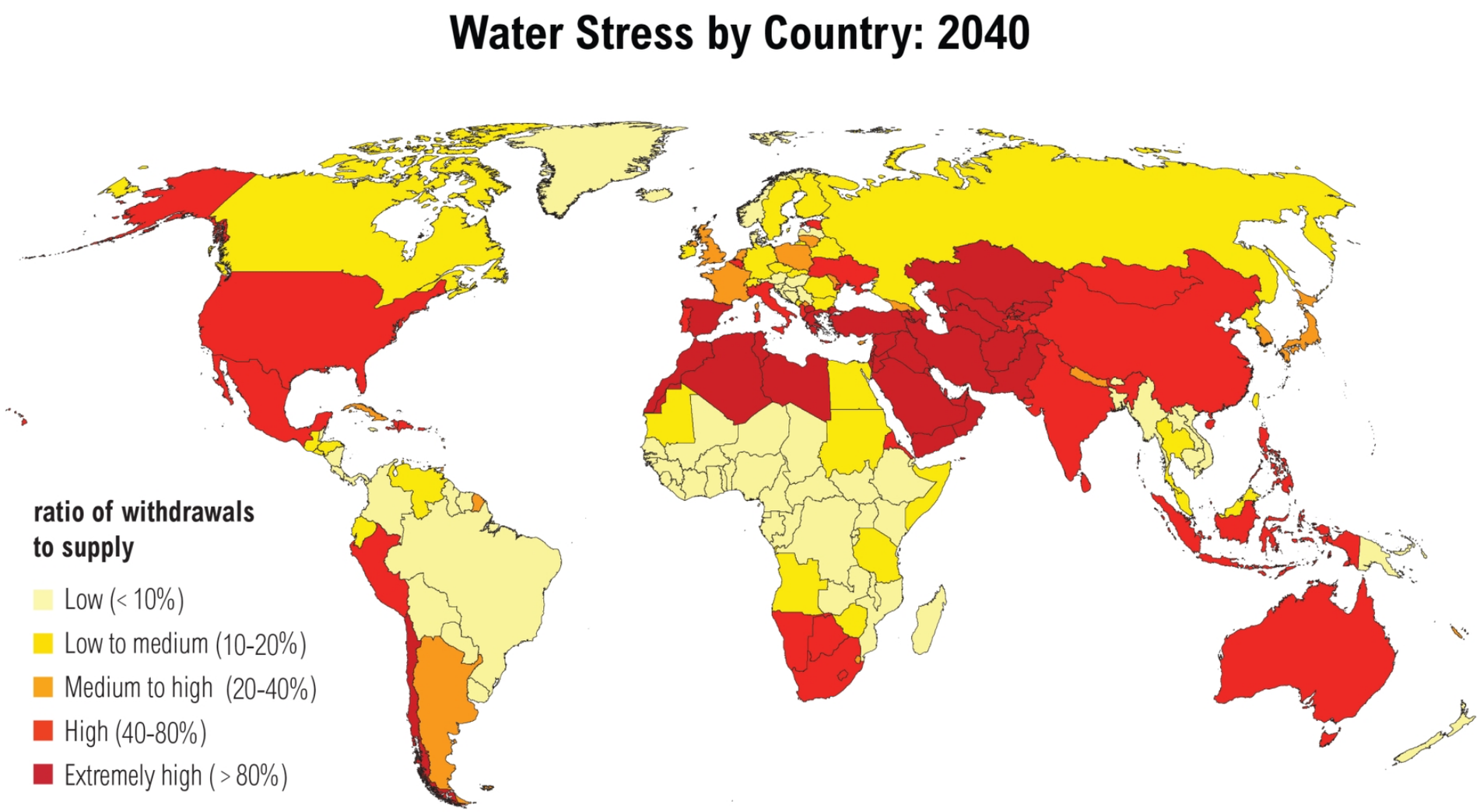

1.1. Some facts about MENA by the WB

- MENA is a global hotspot of unsustainable water use, especially of groundwater. In some countries, more than half of current water withdrawals exceed what is naturally available;
- 82% of wastewater is not recycled, presenting a massive opportunity to meet water demands;
- The region has the greatest expected economic losses from climate-related water scarcity, estimated at 6–14 percent of GDP by 2050;
- Despite its scarcity, the region has the world's lowest water tariffs and the highest proportion of GDP (2 percent) spent on public water subsidies;
- Flood and drought risks are increasing and are likely to harm the poor disproportionately;

1.1. Some facts about MENA by the WB

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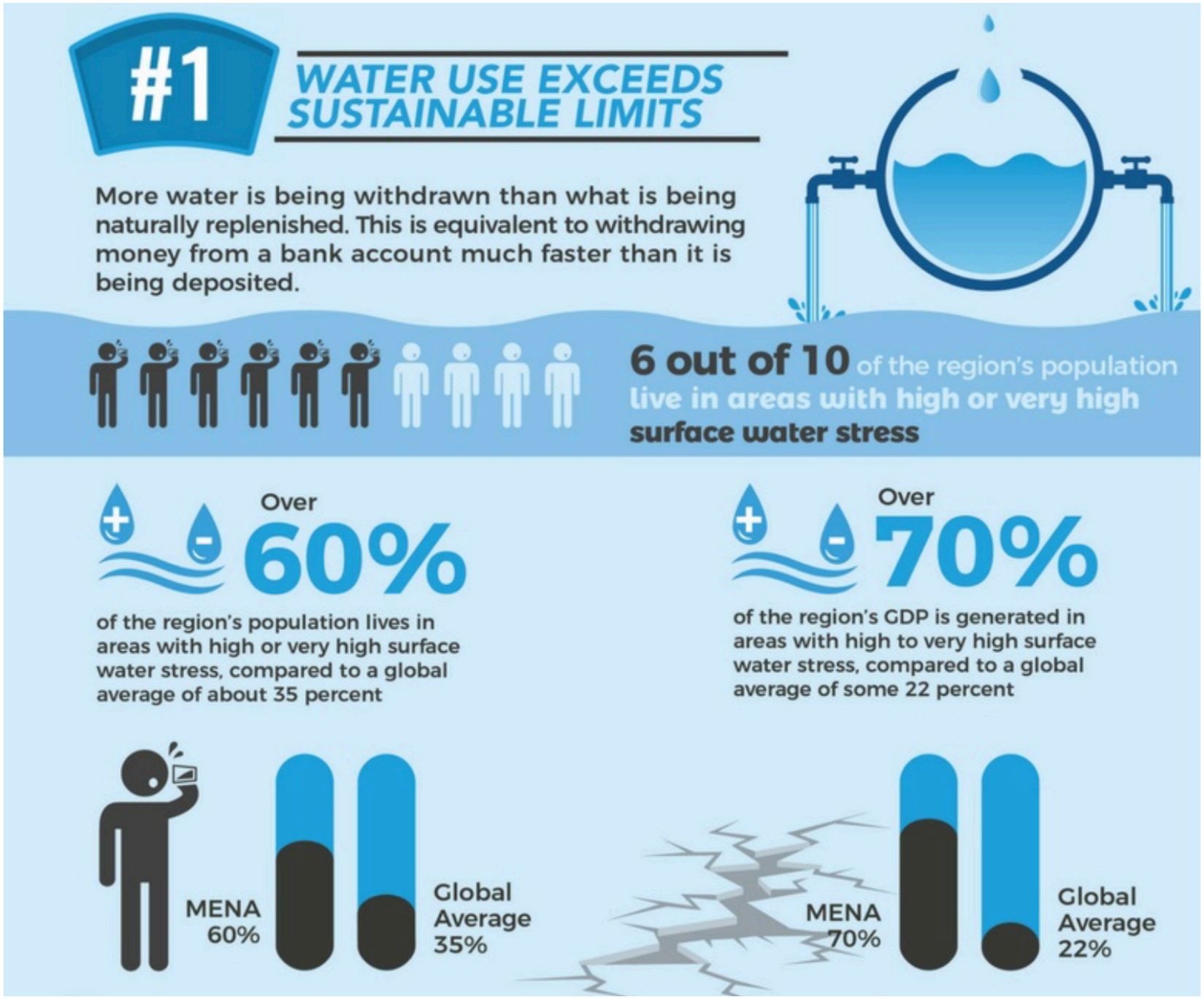
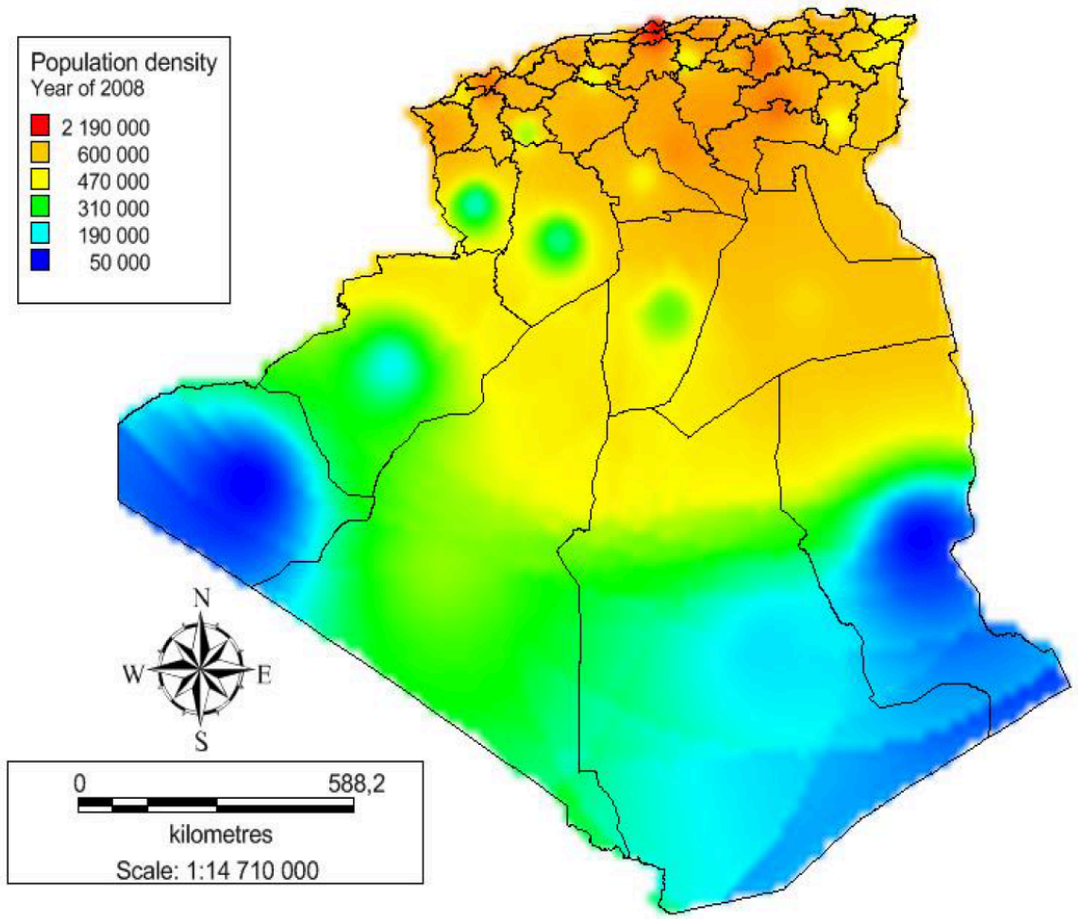
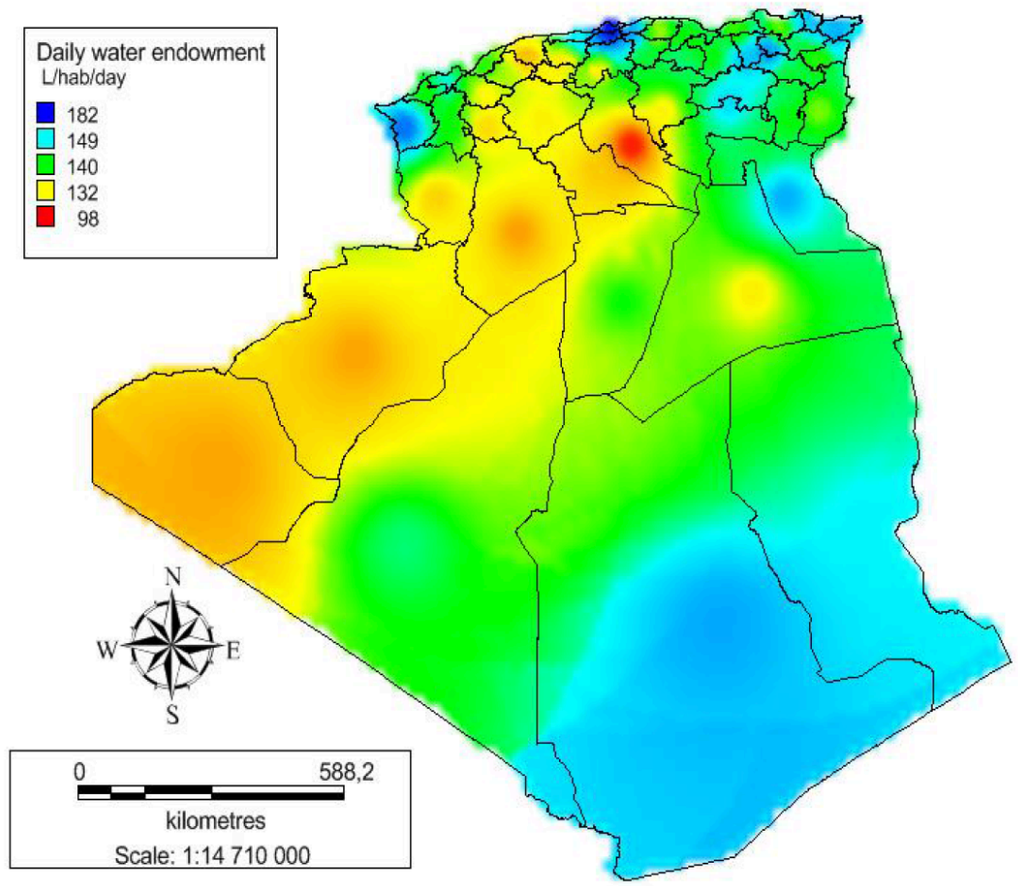


Source: World Bank (Aug 2017)

1.2. Some facts about Algeria





Source: S.E. Ali Rahman, C. Brahim, *Water Supply Prediction for the Next 10 Years in Algeria: Risks and Challenges,* Irrigat Drainage Sys Eng 2017, 6:3

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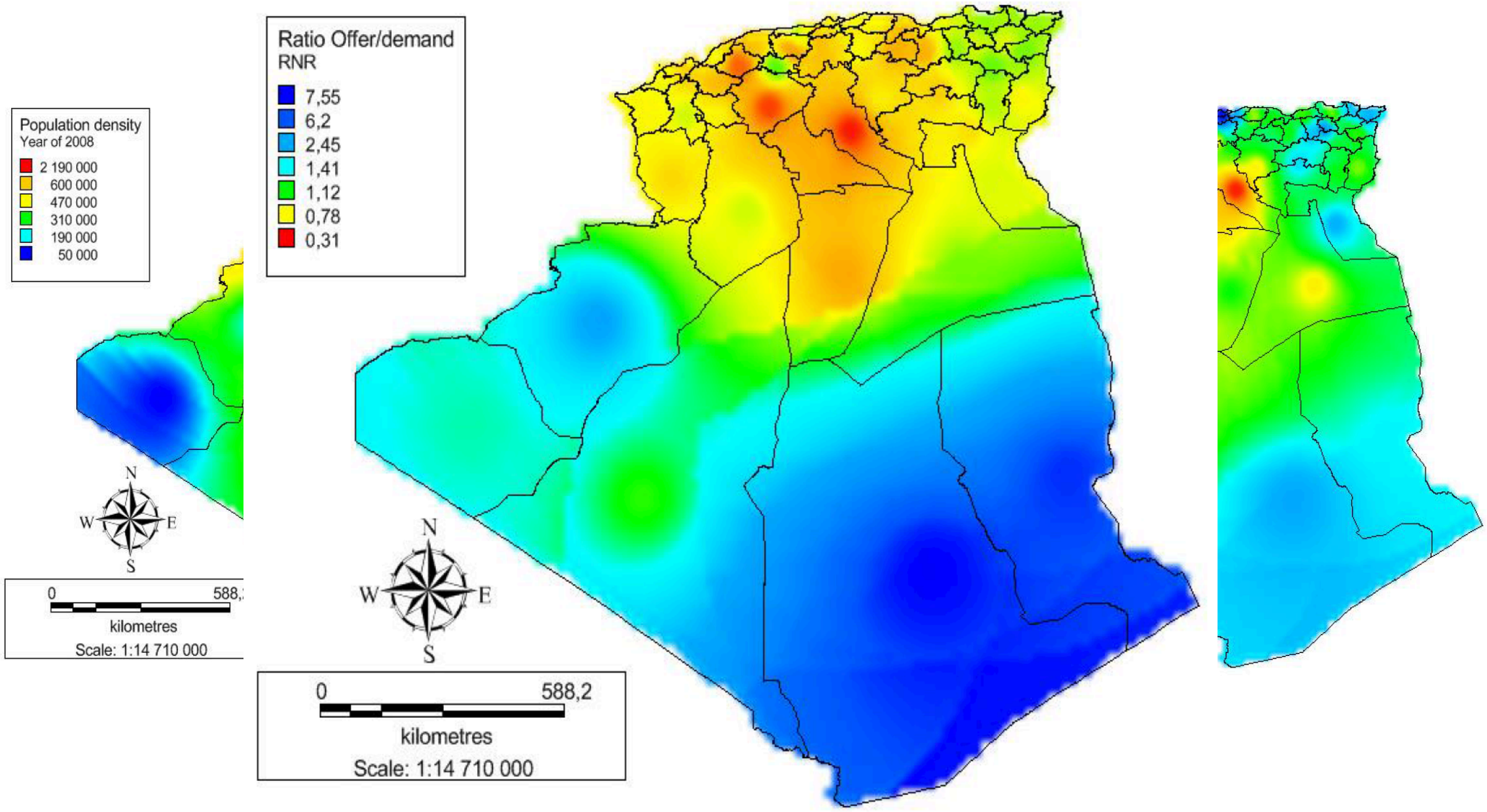

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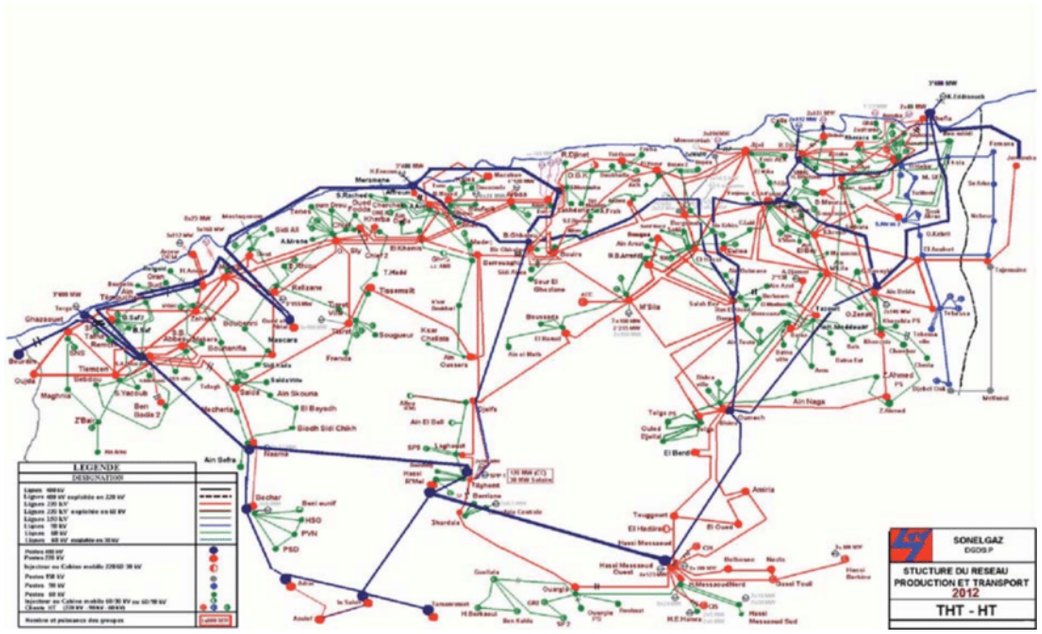
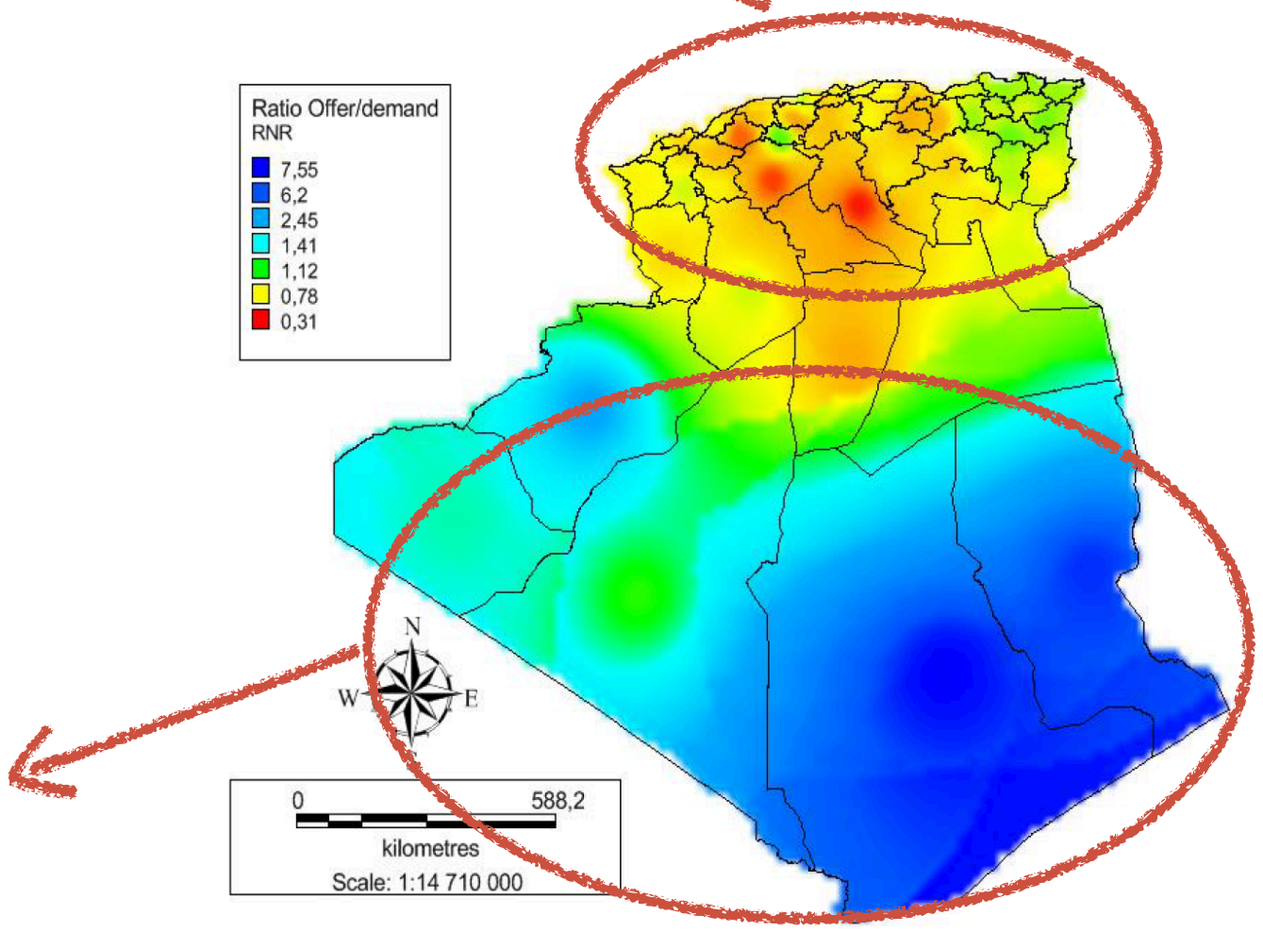
1.2. Some facts about Algeria

Large communities
Higher water stress
Access to grid



Small communities
Low water stress
No access to grid

Large-scale desalination
powered by the grid



Small-scale, off-grid desalination
driven by renewable energy

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1.3. Case study: Ksar Ghilène, Tunisia

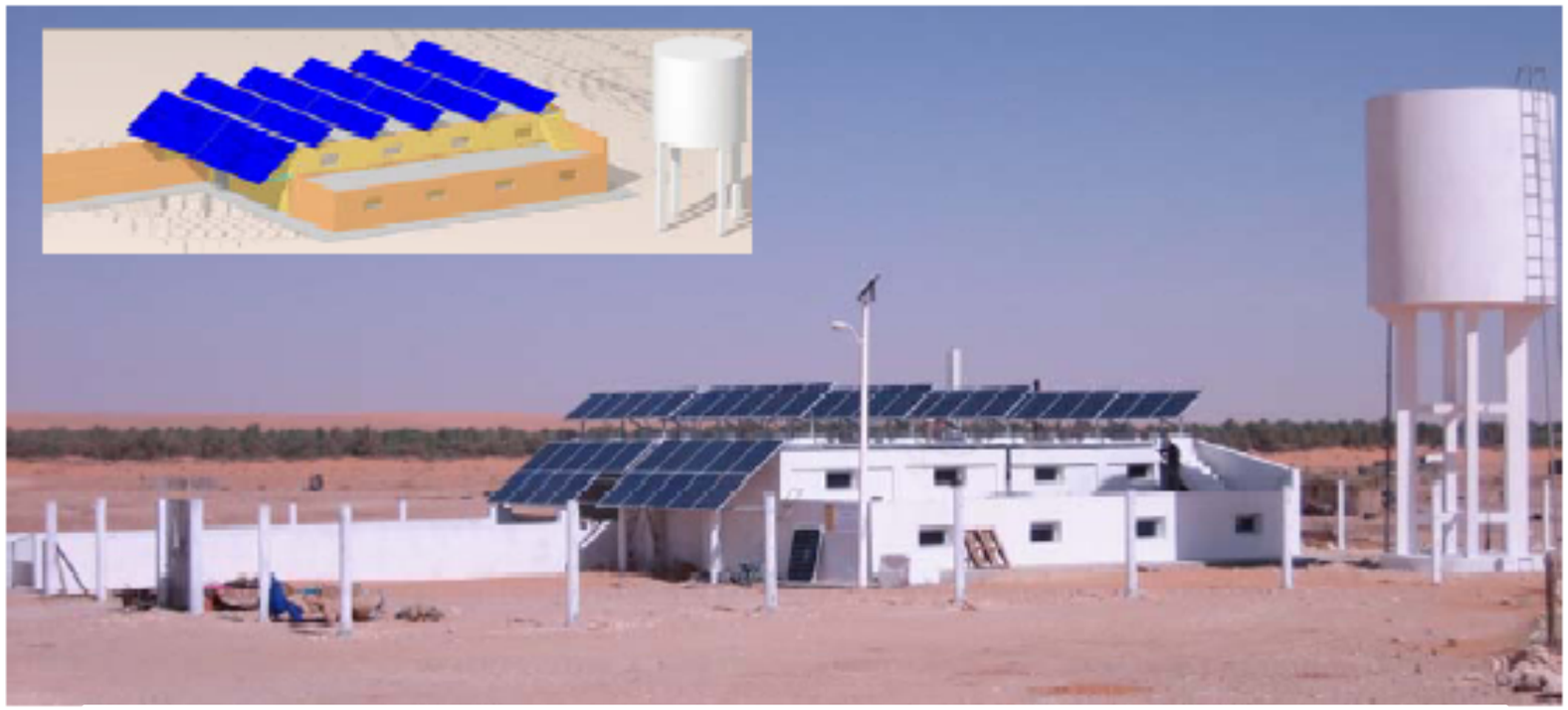
300 inhabitants

150 km from closest grid

60 km from closest fresh water well

Water supply formerly with trucks

1.3. Case study: Ksar Ghilène, Tunisia



Courtesy: Canary Islands Institute of Technology

PV-driven Reverse Osmosis (RO) desalination plant (Brackish water)

10,5 kWp PV facility
50 m^3/day

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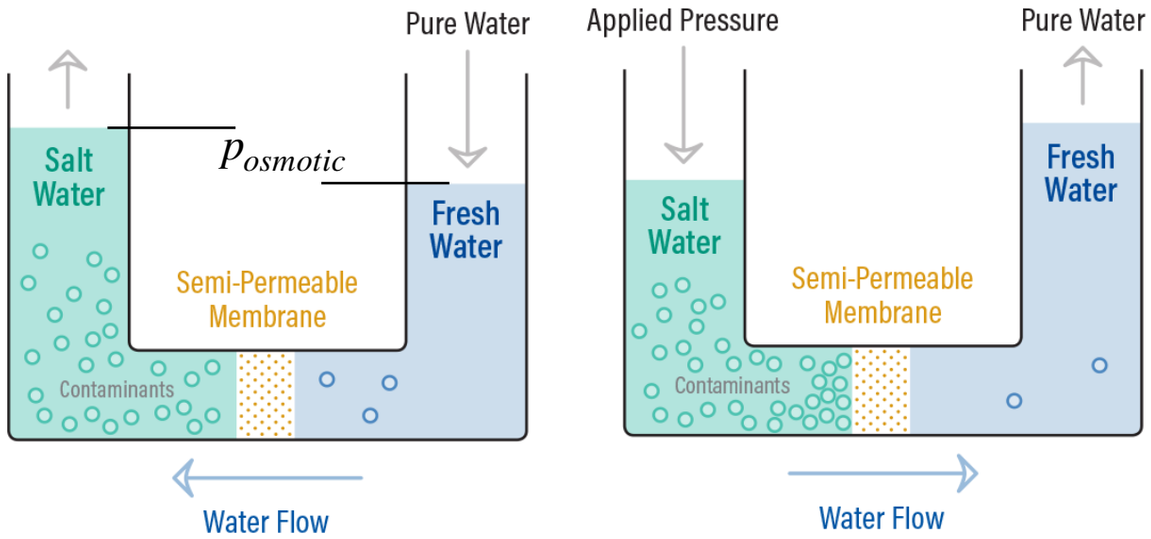
2. RE driven desalination- SoA

- Wind-driven RO desalination: commercially available and cost effective (**<2.5 €/m³**)*
- PV-driven RO desalination: commercially available, higher costs inherent to discontinuous solar energy resources (**3-3.5 €/m³** for 2000 hours/year @full load)

Sea Water Reverse Osmosis (SWRO)



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2. RE driven desalination- SoA

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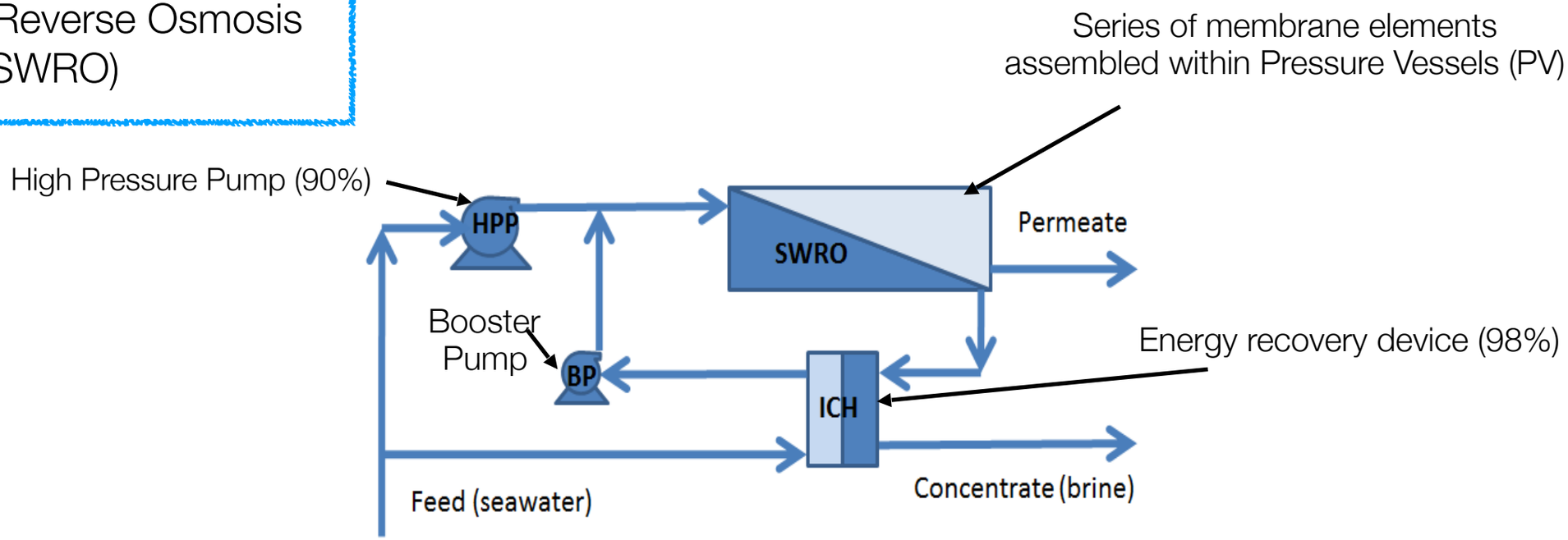
- PV-driven RO desalination: commercially available, higher costs inherent to discontinuous solar energy resources (**3-3.5 €/m³** for 2000 hours/year @full load)
- Wave energy-driven RO desalination in development. No technical bottlenecks
- CSP-driven desalination unfeasible due to costs and auxiliary power consumption

Sea Water Reverse Osmosis (SWRO)



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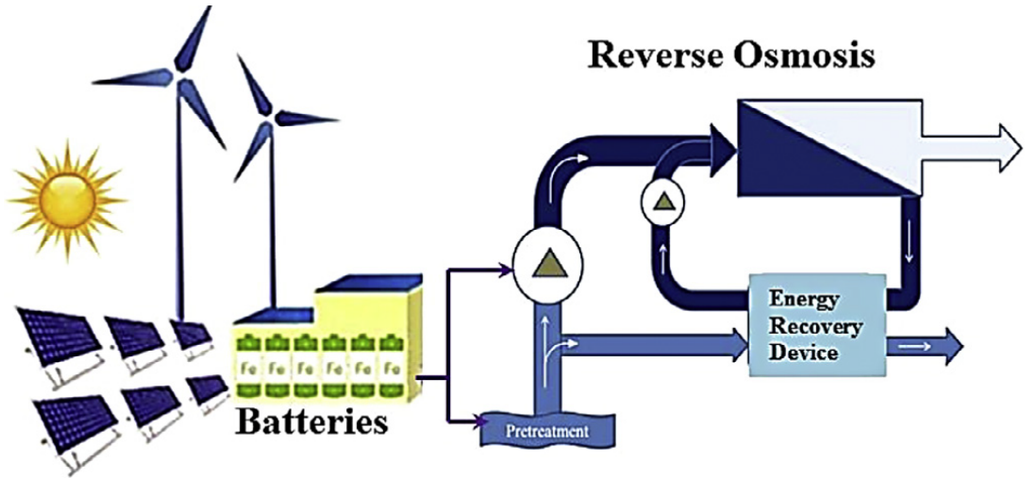
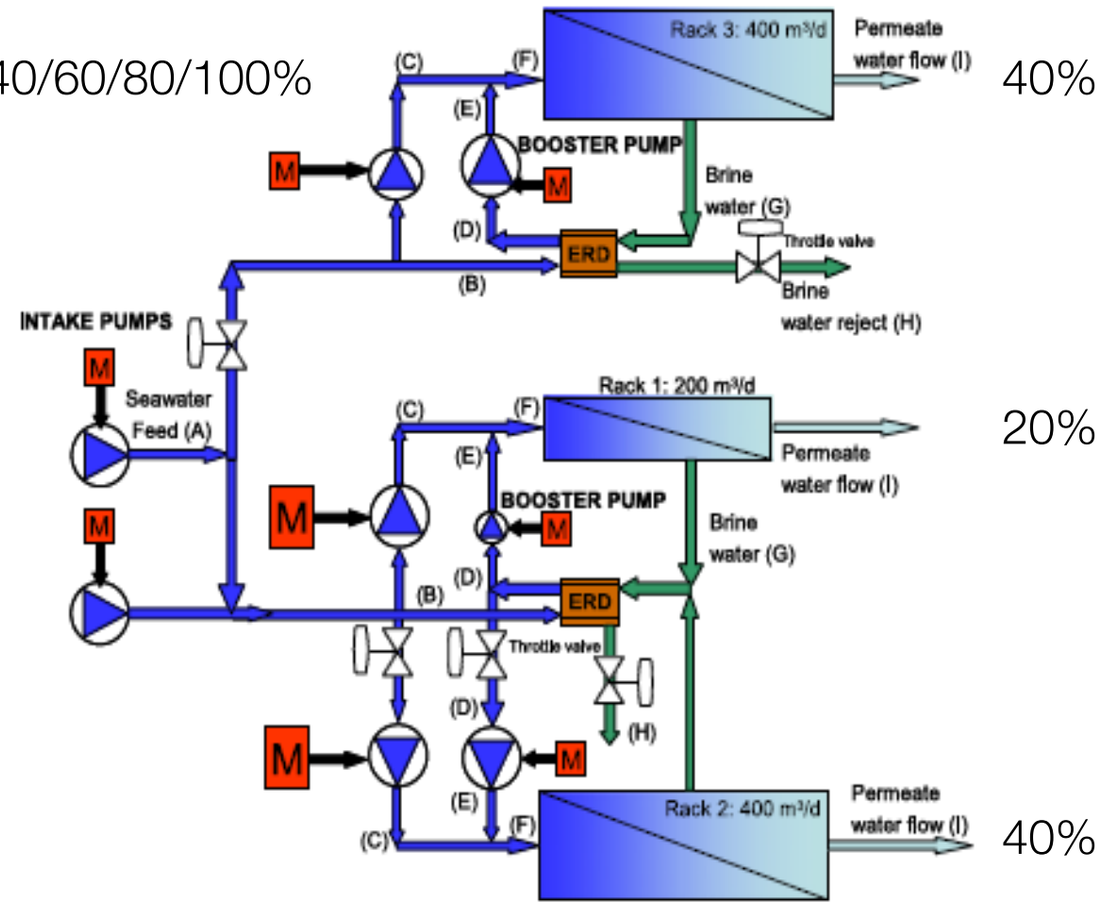
2.1. Commercially available technologies

- PV-driven or Wind-driven SWRO with storage systems:
  - Wind-driven RO: enables operation overnight (if wind available)
  - Wind/PV-driven RO: large batteries to enable operation in a standard on/off mode
  - Wind/PV-driven RO: multiple SWRO plants of the same capacity running in parallel
  - Wind/PV-driven RO: modular approach with multiple, disimilar units in parallel



Standard approach

20/40/60/80/100%



40%

20%

40%

Source: B. Peñate, F. Castellano, A. Bello, L. García-Rodríguez, *Assessment of a stand-alone gradual capacity reverse osmosis desalination plant to adapt to wind power availability: A case study,* Energy 36 (2011) 4372-4384

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2.1. Commercially available technologies

Wind SWRO: 8000 €/m³/day

Low-cost PV SWRO DESSOL+ (2017)

Source:. García-Rodríguez, *Renewable energy applications in desalination: state of the art,* Solar Energy 75 (2003) 381-393

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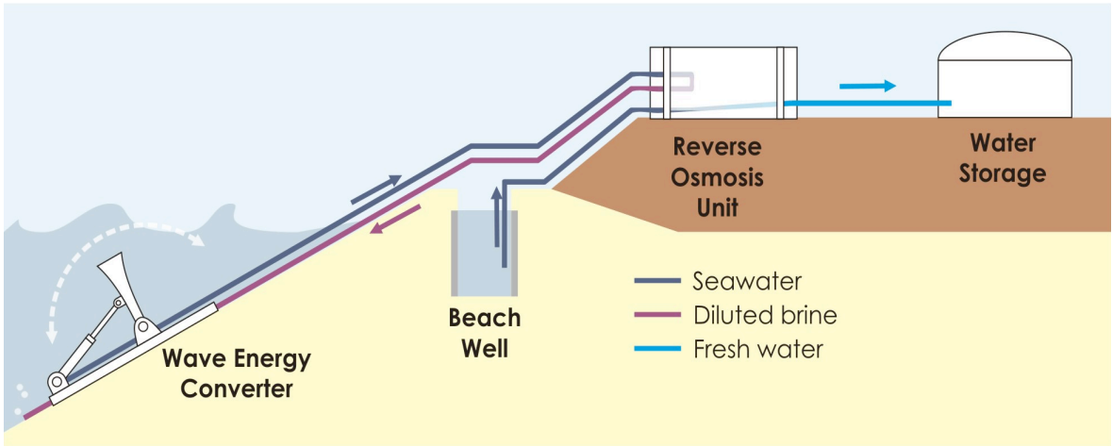
2.2. Technologies under development



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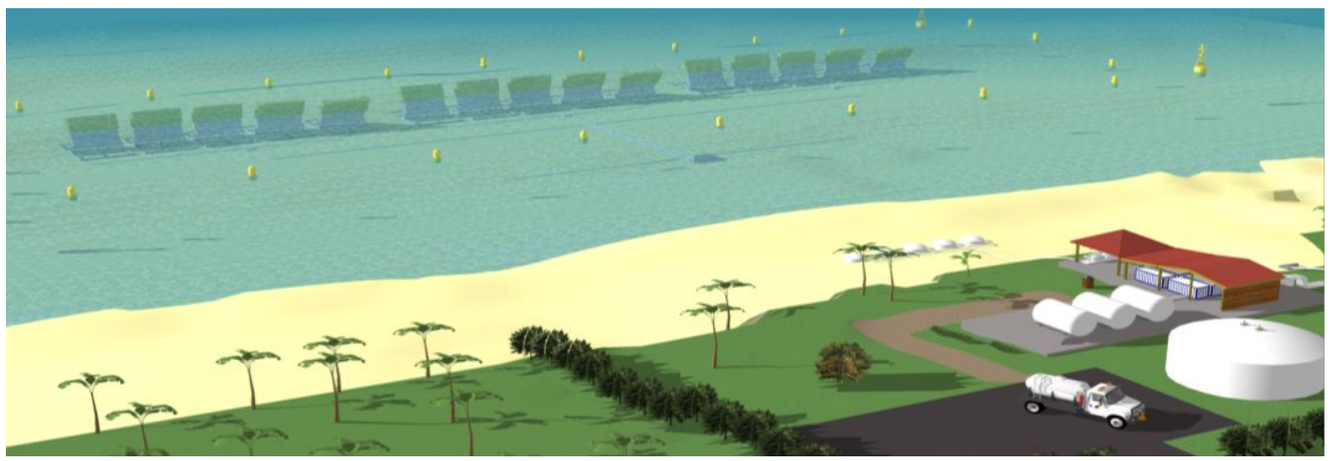

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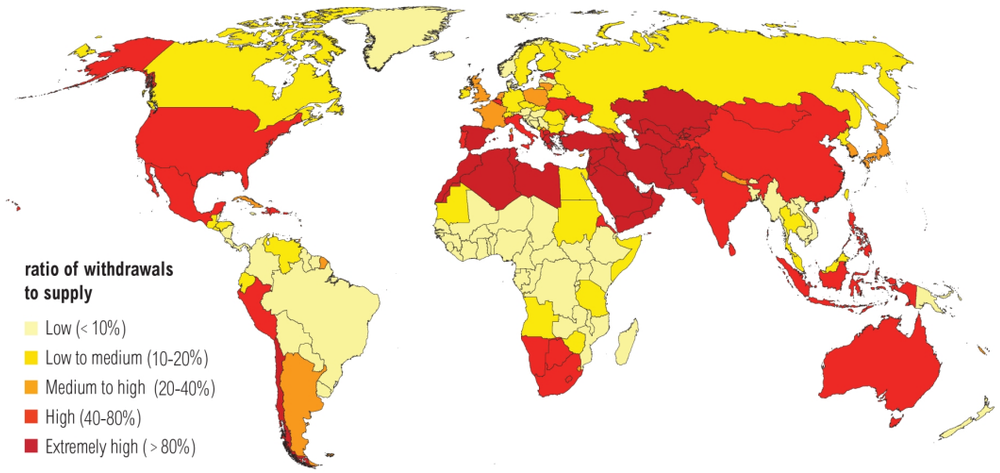
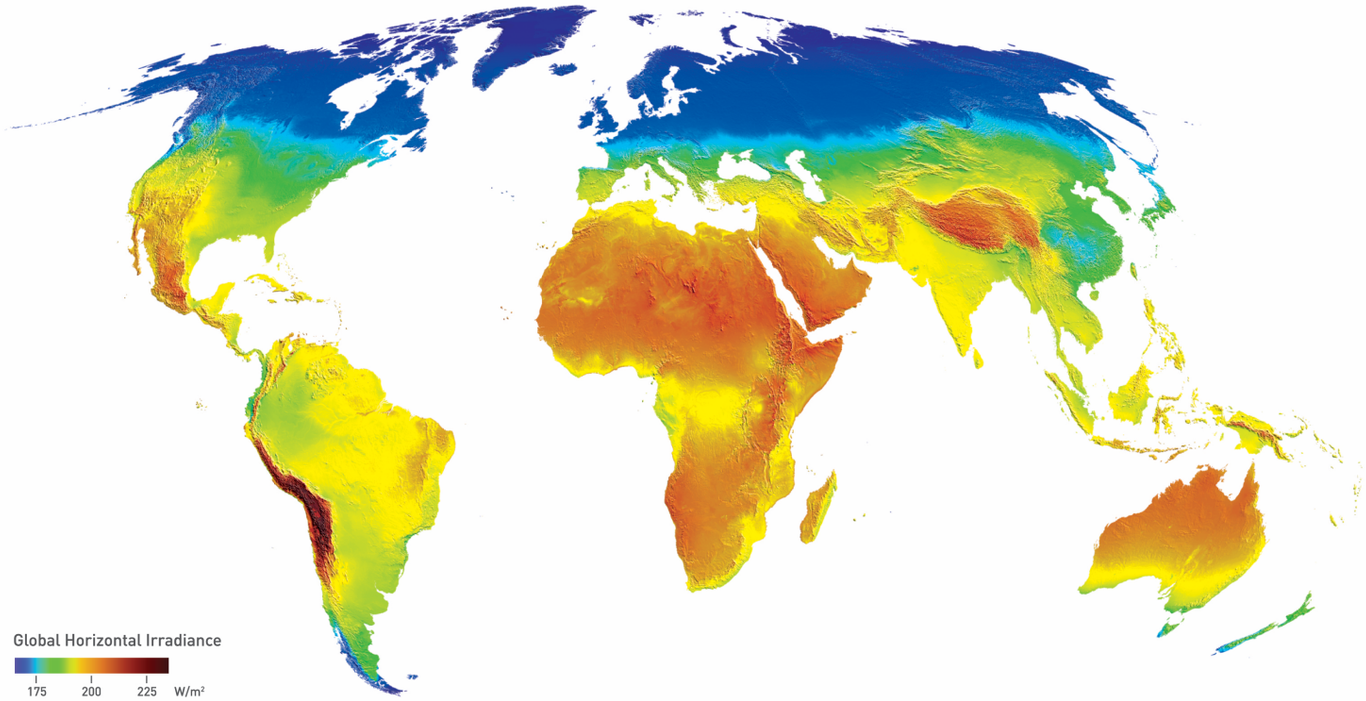
3. Interest of solar desalination



Global Mean Solar Irradiance

- Remember water stress levels projected for 2040?
- The region subjected to the most severe stress is very similar to the sun-belt



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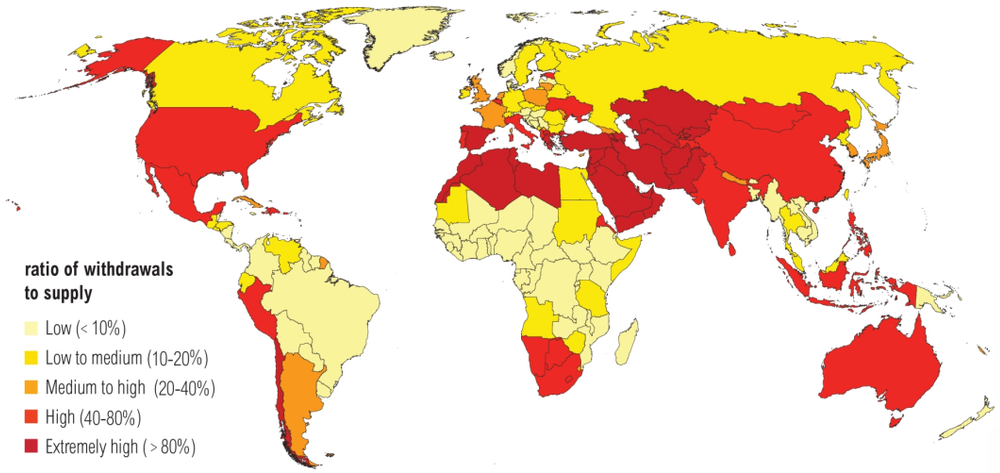
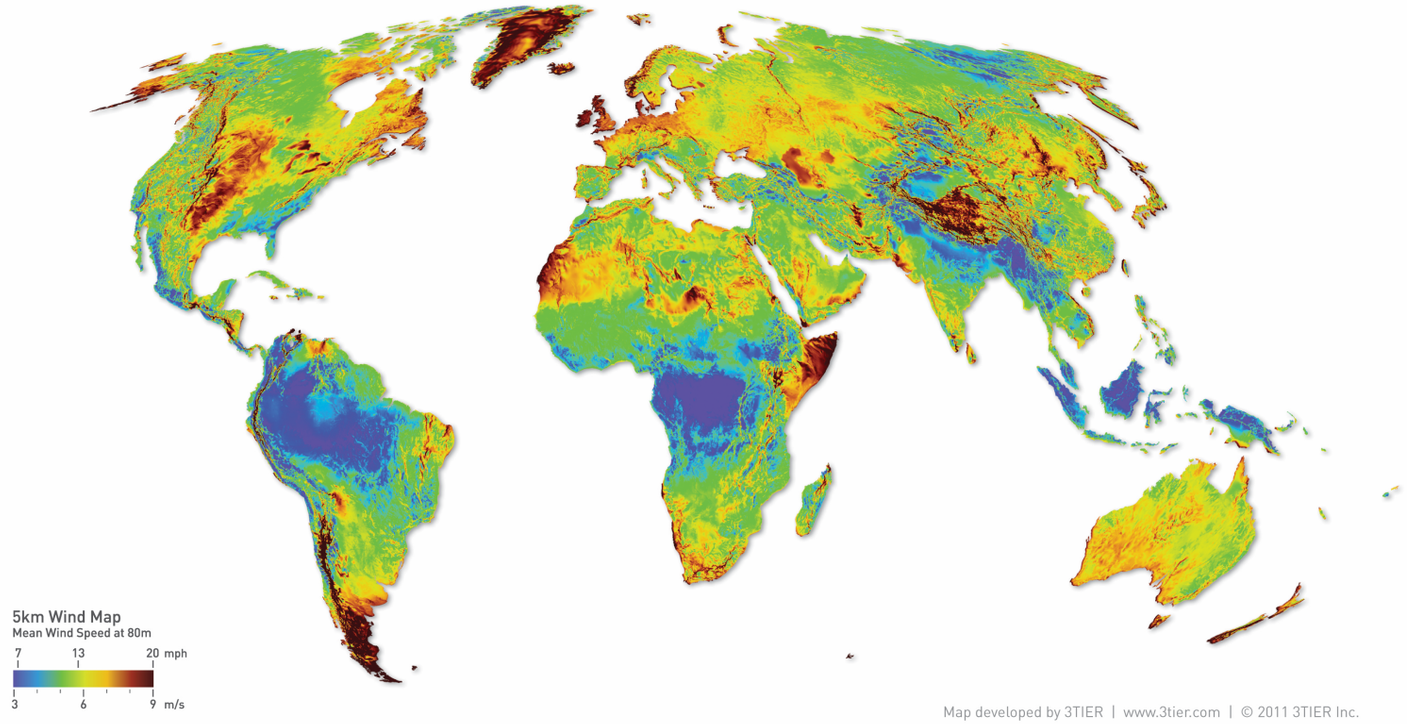


- Remember water stress levels projected for 2040?
- The region subjected to the most severe stress is very similar to the sun-belt
- But this is not the case for wind

Global Mean Wind Speed at 80m



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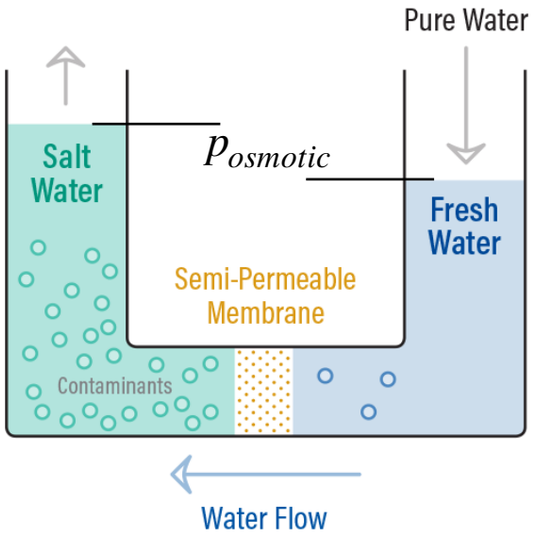
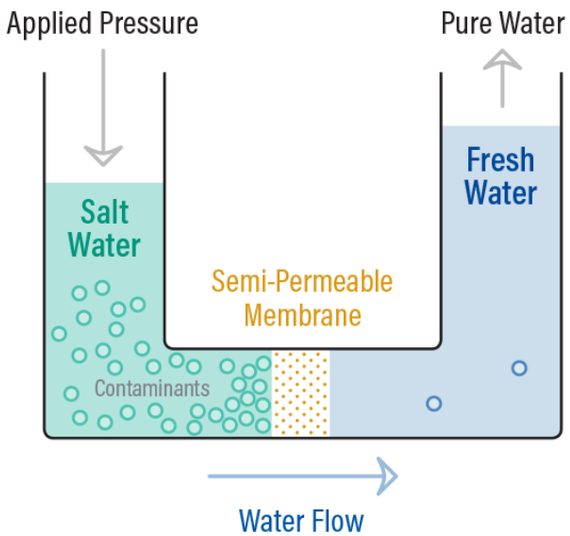
3.1. Solar desalination: Overview -RO-

Reverse Osmosis (RO): Electricity, (2+1) kWh/m^3
(Club Lanzarote Playa Blanca, Lanzarote)



Forward osmosis



Reverse osmosis

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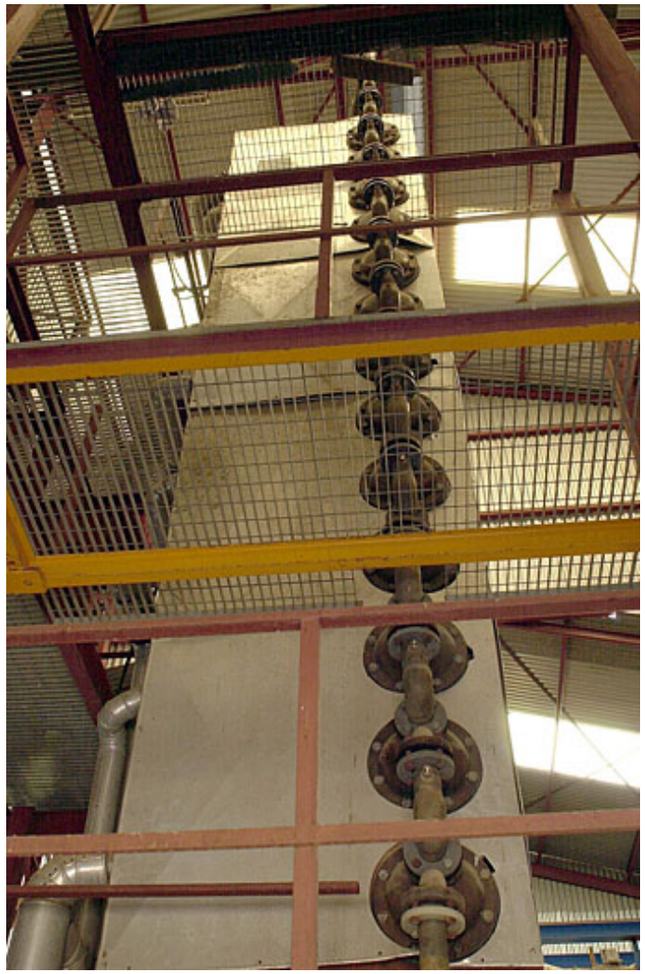
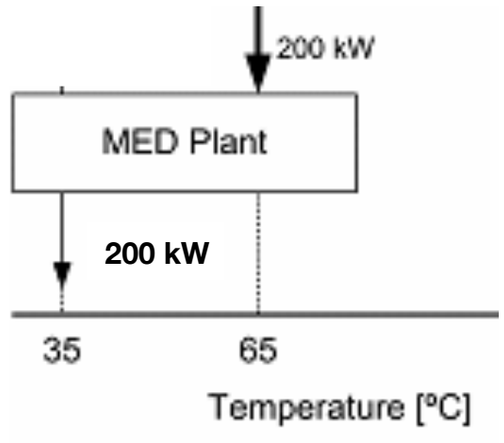
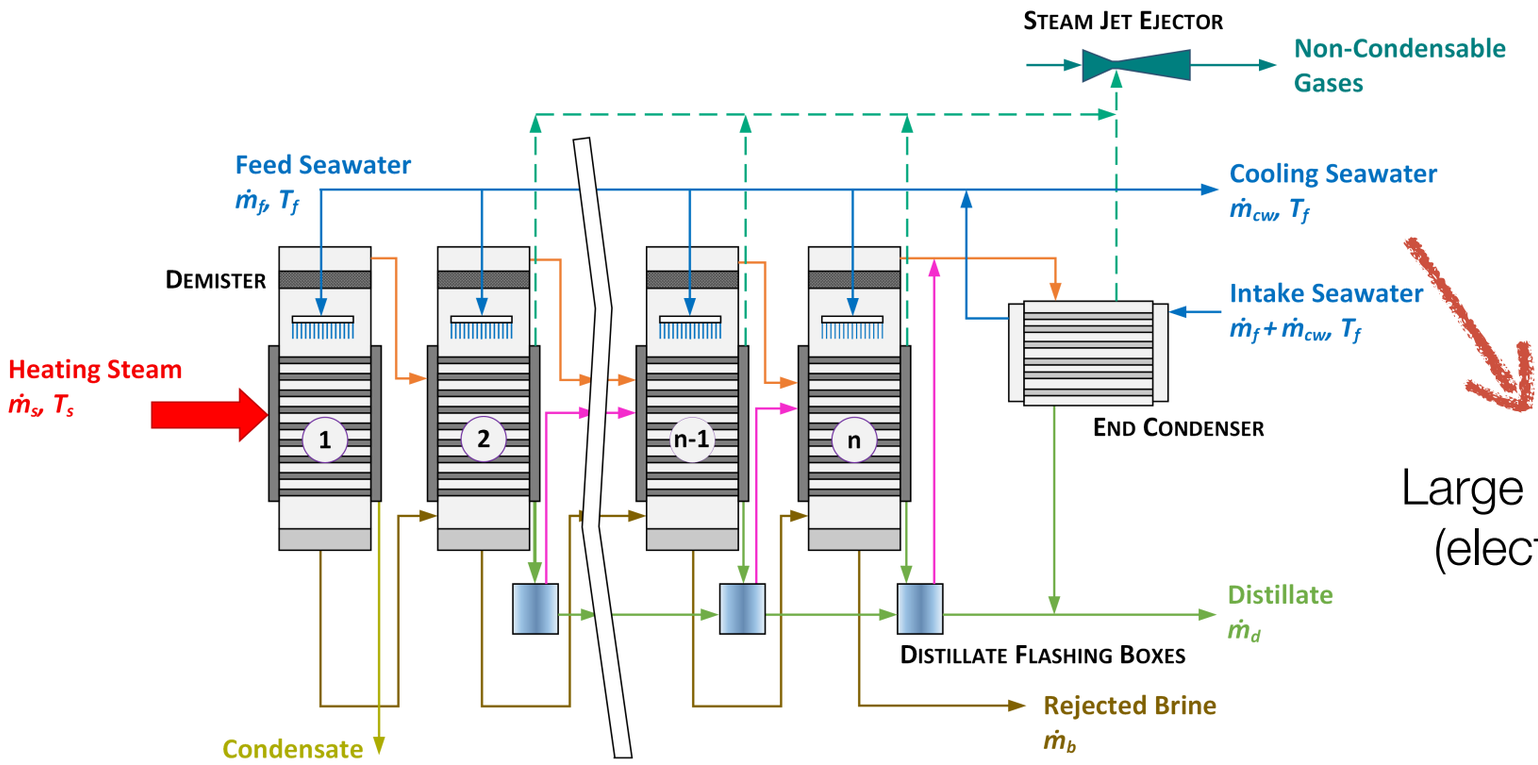
3.2. Solar distillation: Overview -MED-



Water production:
3 m³/h

Multi-effect distillation (MED)
–PSA- CIEMAT -
Heat source, 70ºC 230 MJ/m³
Electricity, 2.2 kWh/m³ due to cooling flow (seawater)





Large cooling flow
(electric power)

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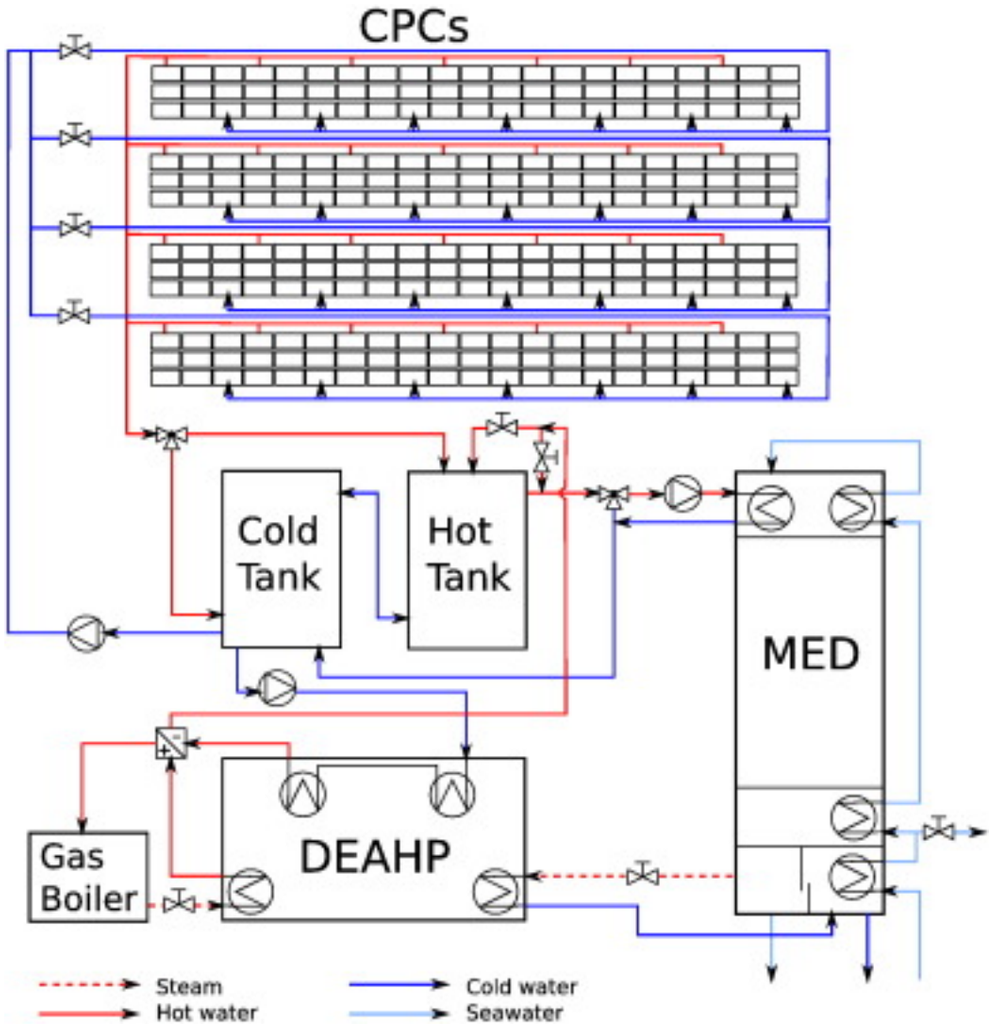
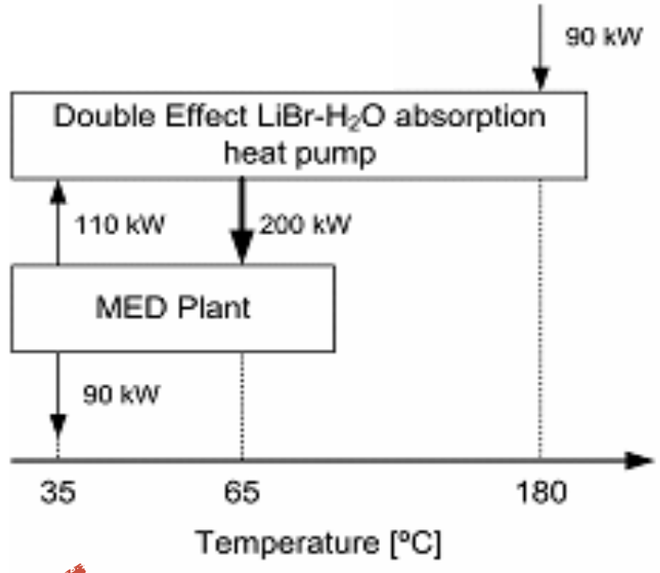


CONCEPT: MED & DEAHP

Heat source, 180ºC 115 MJ/m^3

Electricity, 1 kWh/m^3

Water production: 3 m^3/h



No cooling flow needed
Specific energy halved

Source: A. de la Calle, J. Bonilla, L. Roca, P. Palenzuela, *Dynamic modeling and simulation of a solar-assisted multi-effect distillation plant,* Desalination 357 (2015) 65-76

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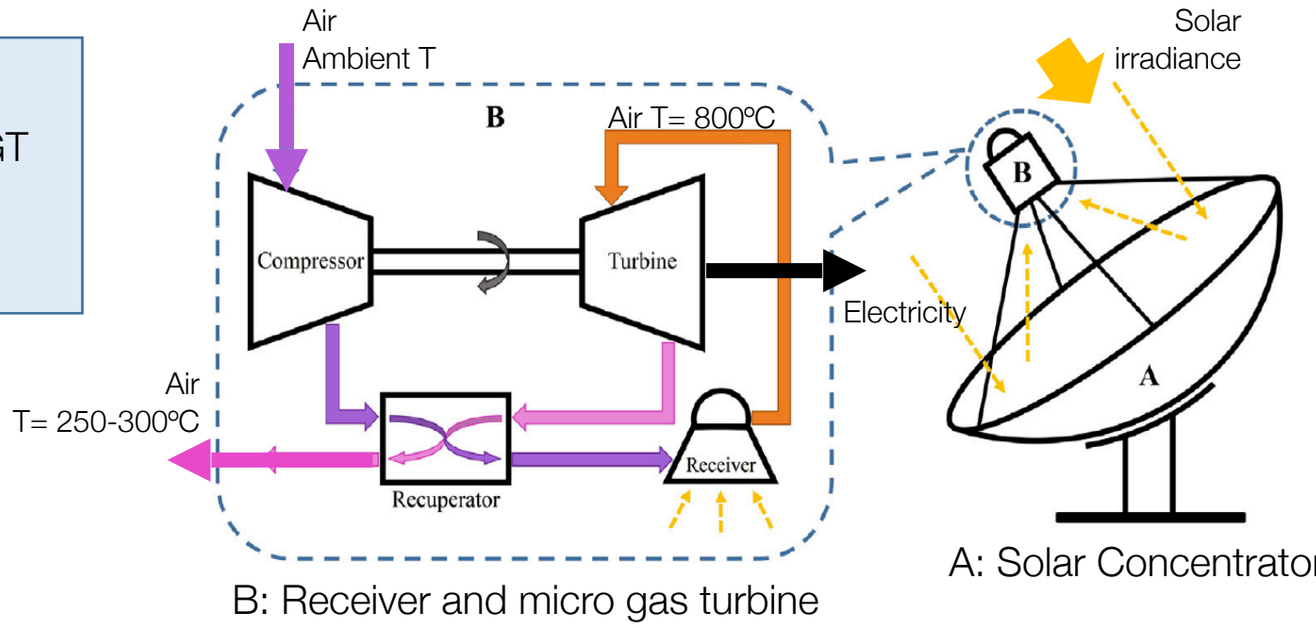
4. Proposed mGT application

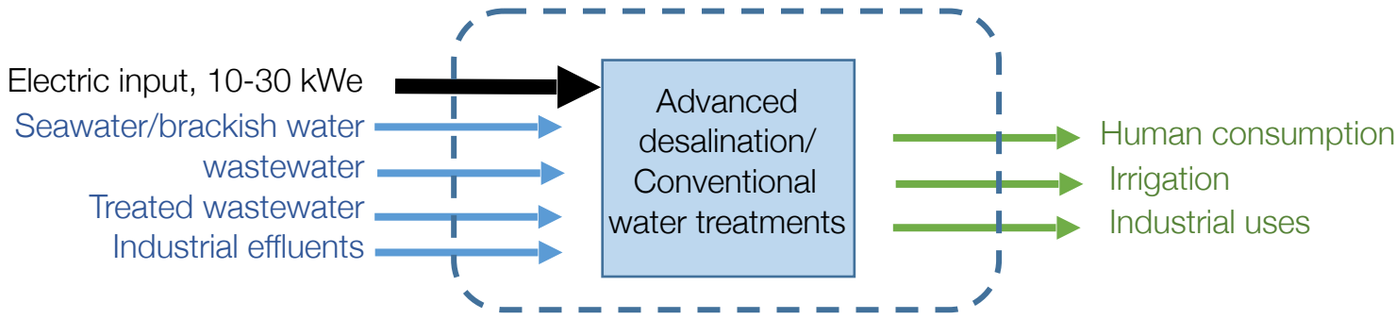
- Unit output 10-30 kWe
- Conventional SWRO: 3.3-10 m^3/h per SMGT
- Possible (parallel) array of SMGTs
- 24/7 operation if backed up by fossil fuel



B: Receiver and micro gas turbine

A: Solar Concentrator

First prototype
ENEA-Italy
(2017)



C: Desalination/Water treatment system

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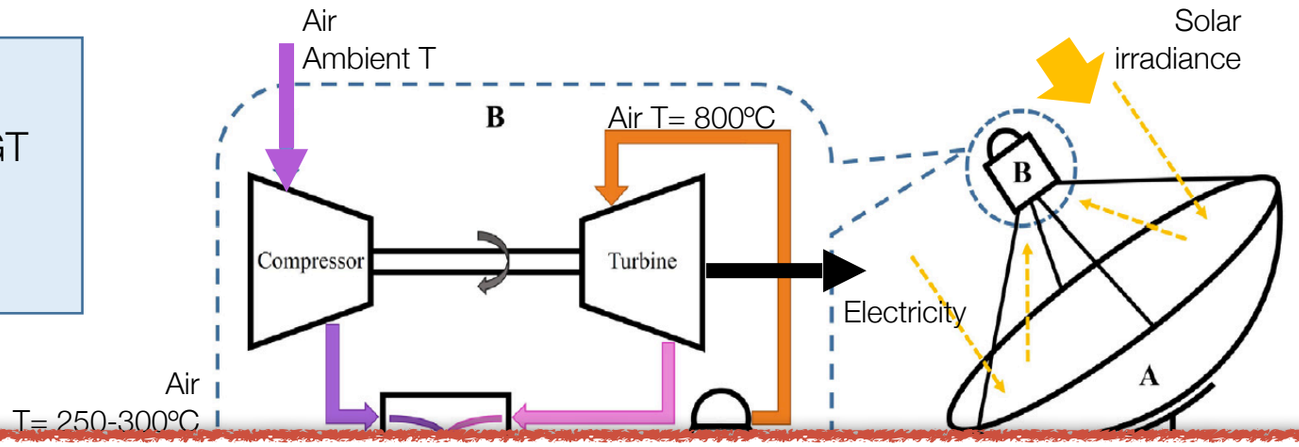
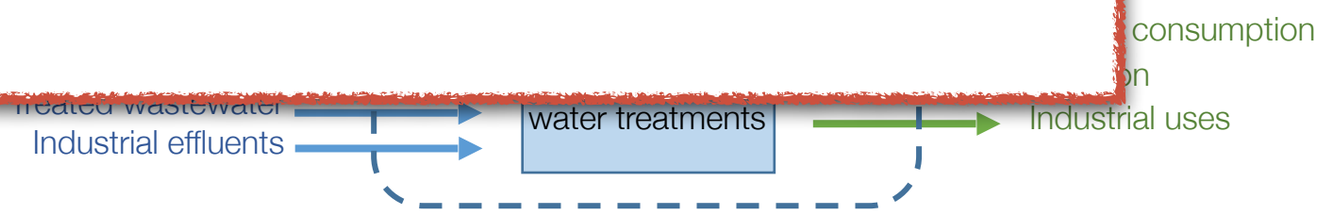


First prototype
ENEA-Italy
(2017)

Better than PV???



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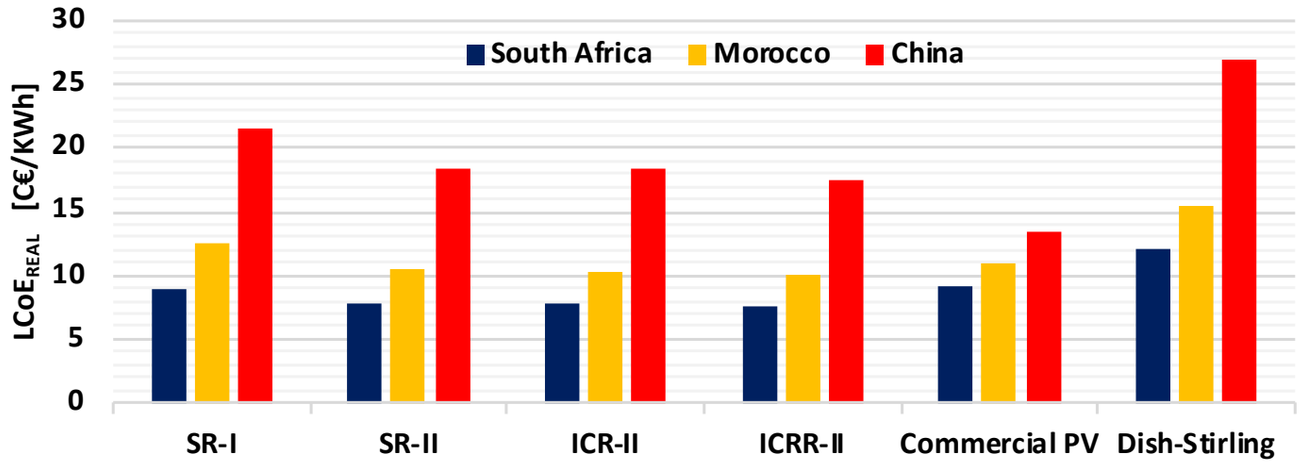
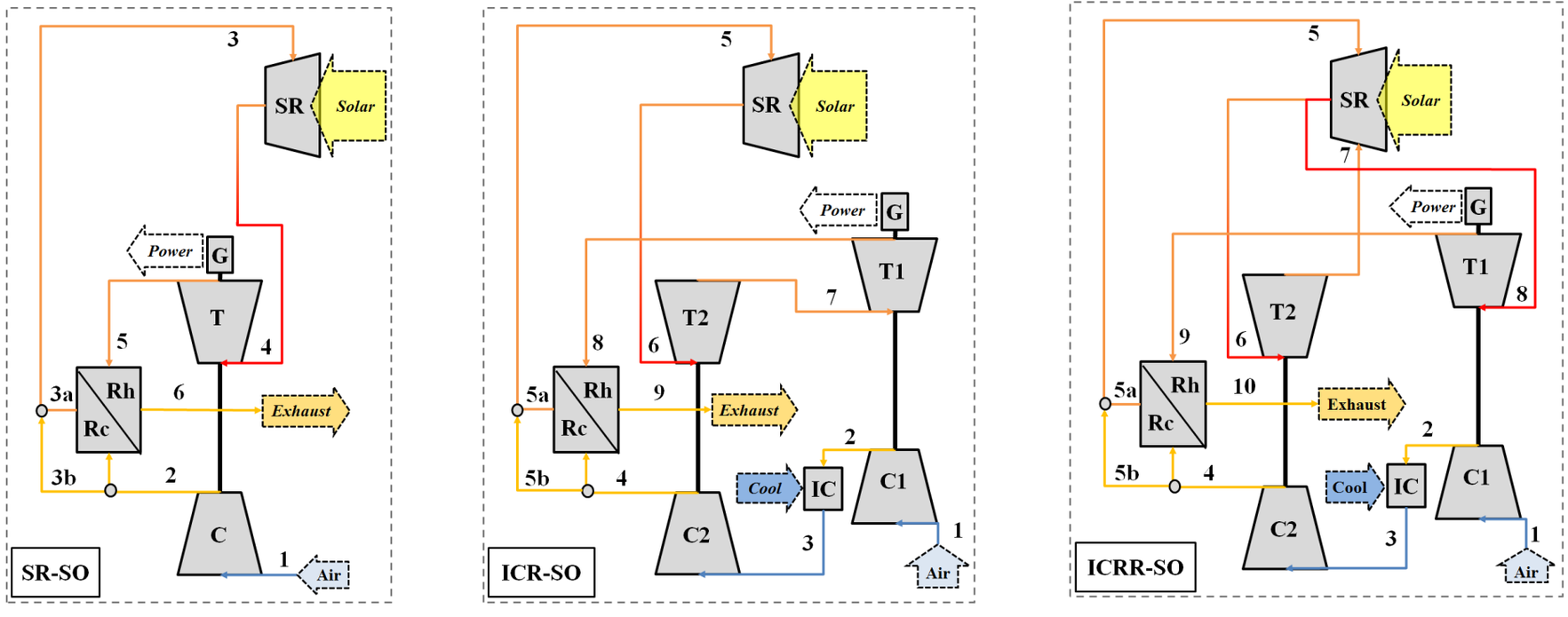
Source: G. Gavagnin, D. Sánchez, J.M. Rodríguez, A. Muñoz, G.S. Martínez, *Economic Competitiveness of Dish-MGT Solar Power Genearators,* Presented at ASME Turbo expo 2017, Charlotte, NC





INCREASING COMPLEXITY

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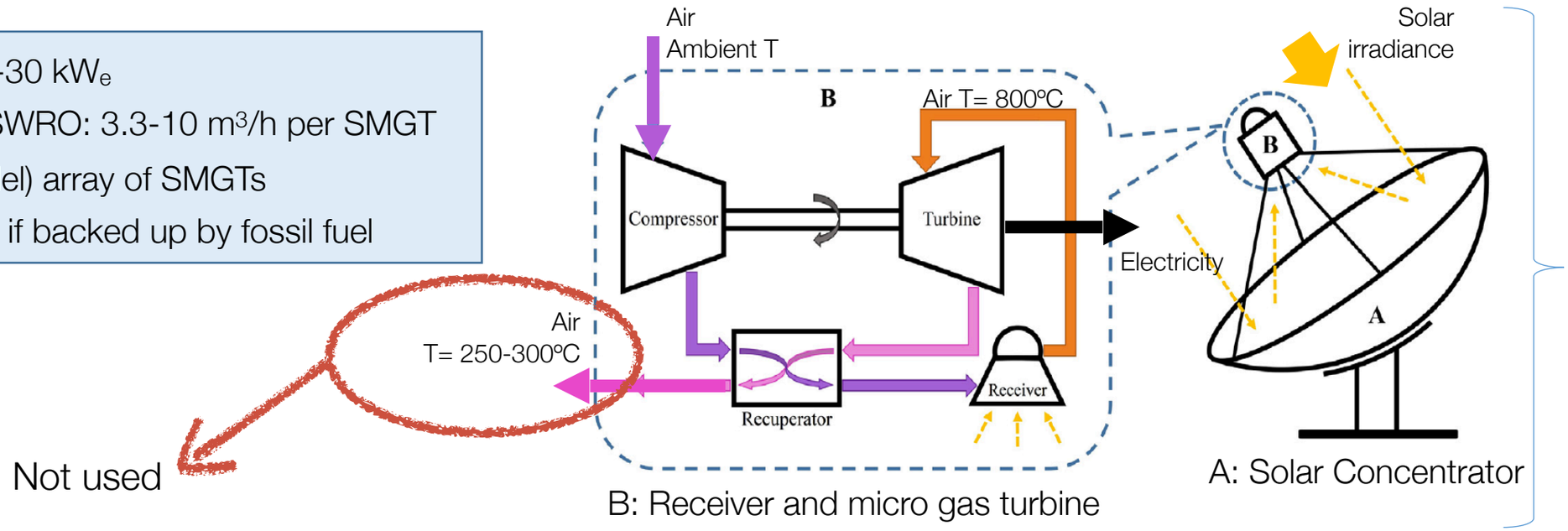

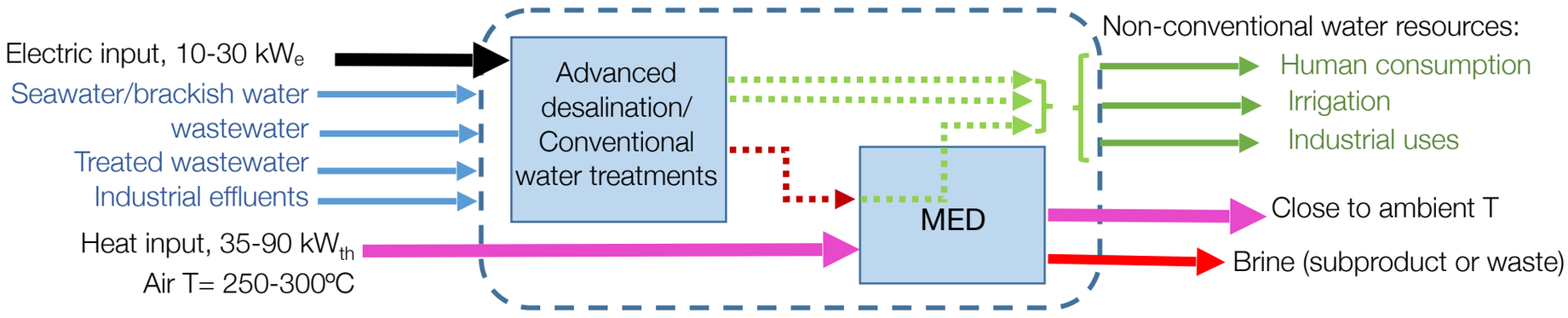

C: Enhanced Desalination/Water treatment system

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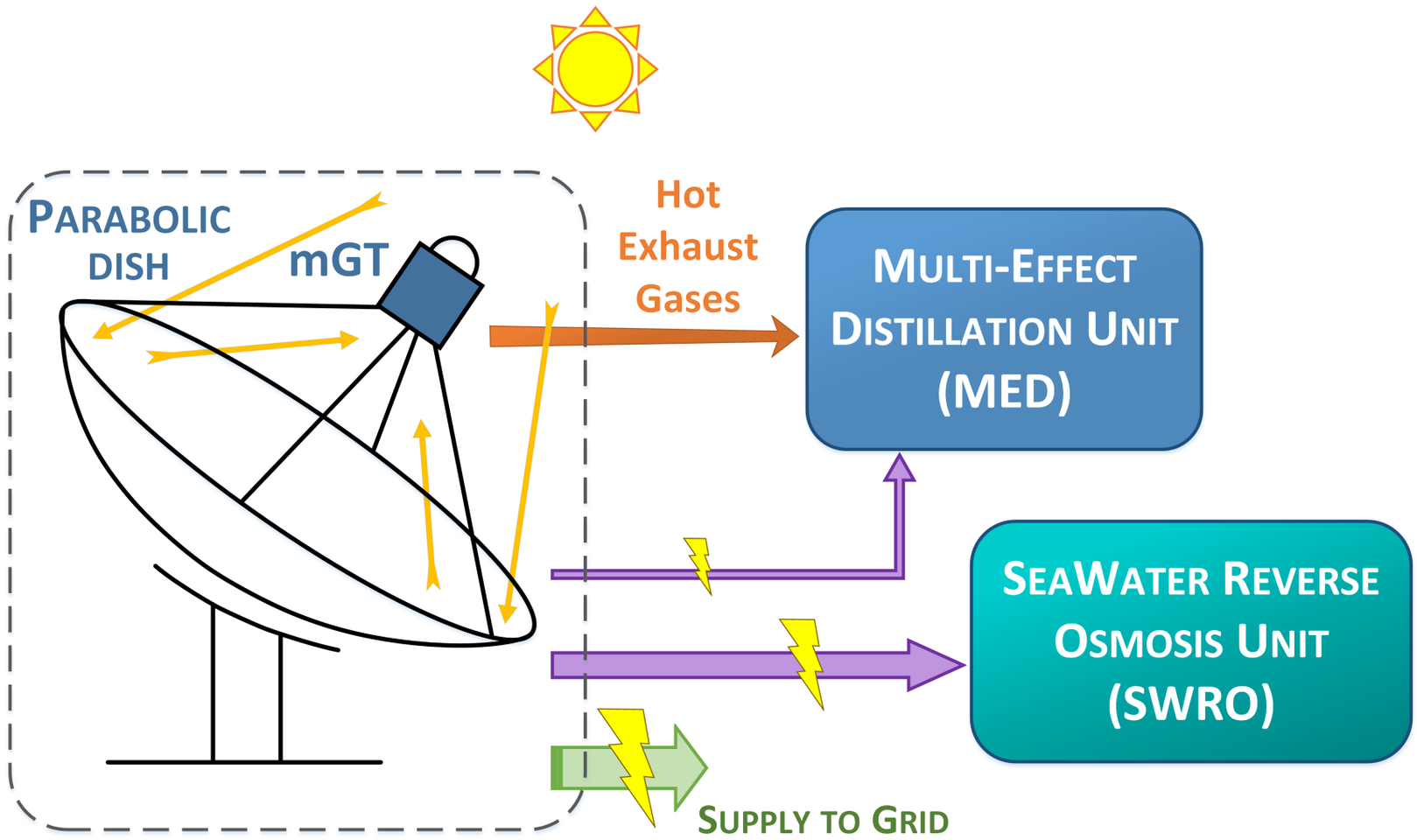
4.1. Desalination driven by SMGT (hybrid)



Availability of thermal energy enables:

- Concentration of effluent for Zero Liquid Discharge (ZLD) - solid waste
- Complementary distillation system to blend product of two desalination systems (higher production and lower specific electric power consumption)

4.2. Economic assessment (I)

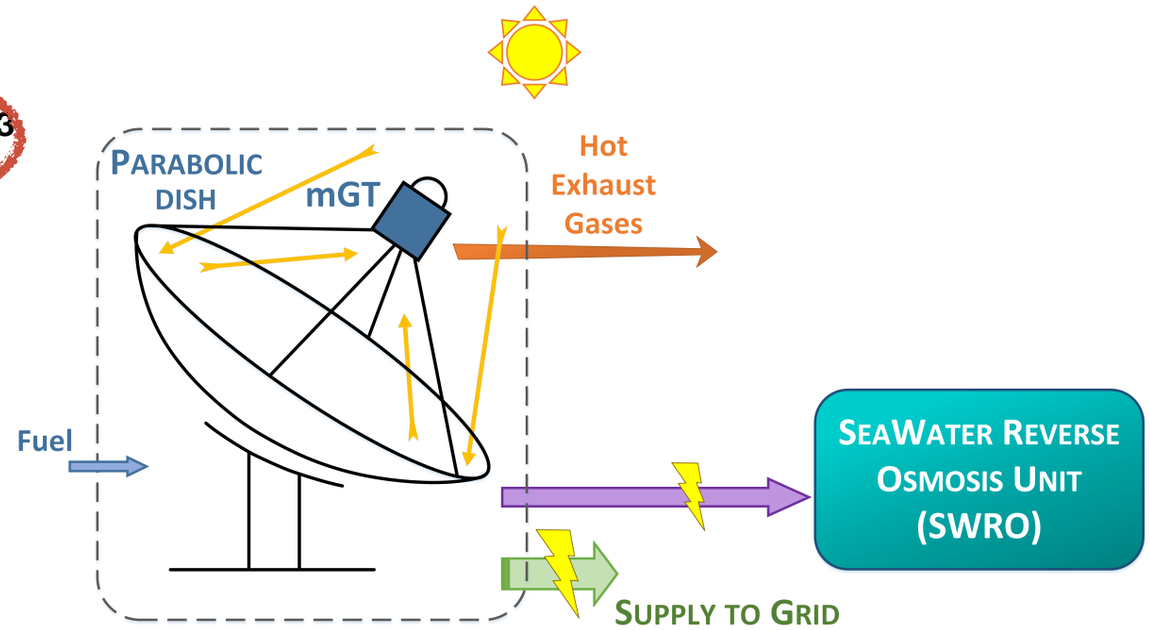
Feed: seawater (40686 ppm & 25ºC)	**MED**	**SWRO**	**SWRO + FWH**	**MED +SWRO**	**SWRO - 2**
			Variable O&M Costs - Cost of Electricity [€/m³]		
South Africa (LCoE=0.078 kWh)	0.19	0.23	0.24	0.17	0.23
Morocco (LCoE=0.104 kWh)	0.25	0.31	0.32	0.23	0.31
China (LCoE=0.183 kWh)	0.44	0.54	0.56	0.40	0.54
			Fixed O&M Costs [€/m³]		
	0.17	0.33	0.33	0.33	0.33
			Capital cost [€]		
MED (1200 €/m³/d))	31710	0	0	31710	0
SWRO (1000 €/m³/d)	0	26424	26424	26424	52848
Total	*31710*	*26424*	*26424*	*58134*	*52848*
			Case 1 - LCoE=0.078 €/kWh		
Amortisation [€/year]	14215	11846	11846	26061	23692
Annual expenditures - 50% CF [€]	15913	14547	14592	30880	29094
Annual production - 50% CF [m³]	5822	4822	4822	9645	9645
Estimated water cost [€/m³]	**3.30**	**3.02**	**3.03**	**3.20**	**3.02**
			Case 2 - LCoE=0.183 €/kWh		
Amortisation [€/year]	14215	11846	11846	26061	23692
Annual expenditures - 50% CF [€]	15913	14547	14592	30880	29094
Annual production - 50% CF [m³]	5822	4822	4822	9645	9645
Estimated water cost [€/m³]	**3.55**	**3.33**	**3.35**	**3.43**	**3.33**

Source: D. Sánchez, M. Rollán, L. García-Rodríguez, G.S. Martínez, *Solar Desalination Based on Micro Gas Turbines Driven by Parabolic Dish Collectors,* Submitted to ASME Turbo Expo 2019, Phoenix, AZ

4.2. Economic assessment (II)

- A hybrid SMGT can produce water at a cost ranging from **3.0 to 3.5 €/m³**;
- Exploiting the waste heat from the engine in a MED plant is not worth cost-wise;
- The system is thus reduced to SMGT-RO;
- The unit can be sized according to a variable demand of electricity, fresh water and heat;
- Some references:
  - On-grid SWRO: ~0.5 €/m³ (Tawelaah RO IWP Saudi Arabia: 908400 m³/d 0.43 €/m³ 0.076 €/kWh)
  - Off-grid Wind+SWRO (+batteries): 1.2 €/m³
  - **Off-grid PV+SWRO (+batteries): 2.5-3.0 €/m³**

Market opportunity
Worth of flexibility?
Worth of reliability?
Worth of 24/7?



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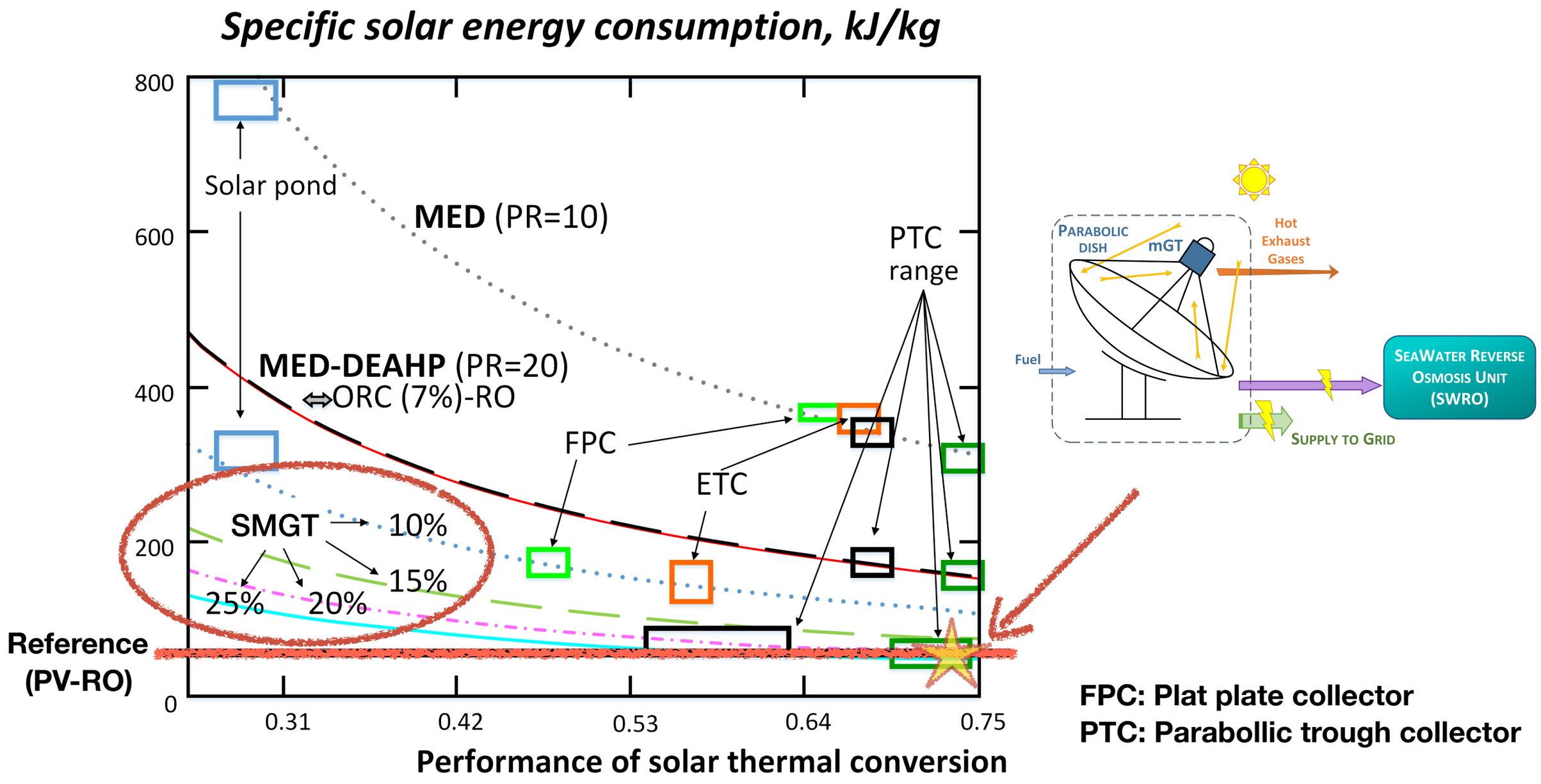
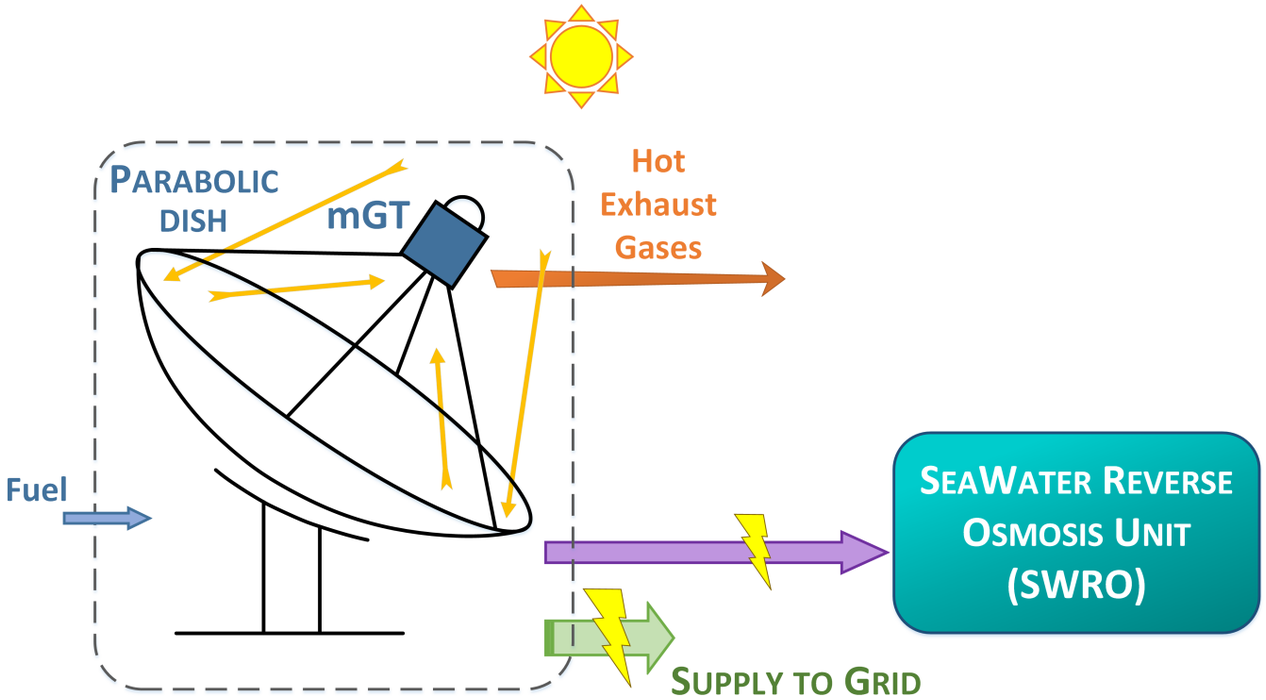
4.3. Thermodynamic background



5. Conclusions

- Desalination based on micro gas turbines feature:
  - Cost-effective water costs: 3-3.5 €/m^3
  - Higher reliability
    - Maintenance driven by RO plant
    - Maintenance-free prime mover (oil-free, long TBO)
    - No need for auxiliary systems (batteries, diesel gensets)
    - 24/7 operation
    - Fuel flexibility
    - No NOx (NG-driven)
    - High grade, clean heat (225ºC)



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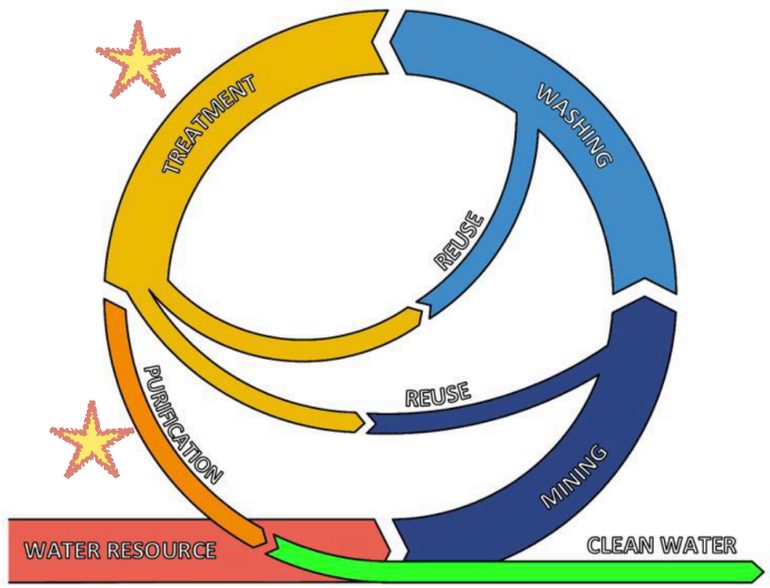
6. Ongoing research

- MSCA - RISE programme - REMIND (2018-2022)
  - Coordinated by University of Callabria
  - 8 partners: Italy, Spain, Chile, Ecuador
  - Budget 1.4 M€

REMIND - **R**enewable **E**nergies for Water Treatment and Reuse in **Mi**ning **Ind**ustries



- Interreg-Atlantic programme - EERES4WATER (2019-2021)
  - Title: '*Promoting the Energy-Water Nexus through Renewable Energy and Energy Efficiency*'
  - Coordinated by Technical Corporation of Andalusia CTA
  - 18 partners: Spain, United Kingdom, Ireland, Portugal, France
  - Budget 3.1 M€

Desalination based on micro gas turbines

Flexible, robust, economical… better?

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