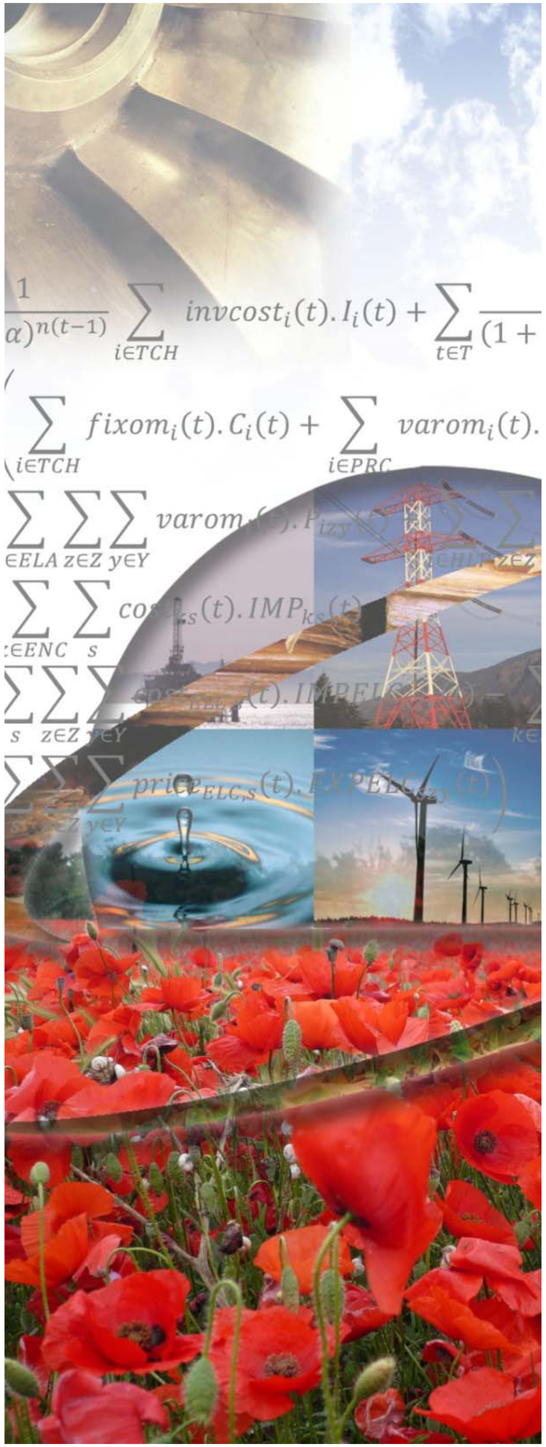

Centre for Applied Mathematics

Modeling water and energy interactions in the long run

Edi Assoumou

Stéphanie Bouckaert, Aurélie Dubreuil

Sandrine Selosse, Nadia Maïzi

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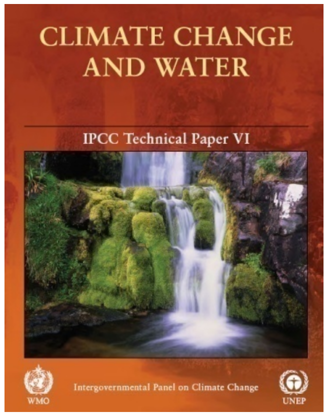
- Overview
- Modeling water requirements for energy production
- Modeling energy requirements for water supply
- Concluding remarks

1. The water – energy nexus

- Water and energy needs are already highly interdependent
- Climate change and sustainability issues add more complexity for the long term
  - Energy related GHG emissions induce climate change
  - Sustainability of water systems is at risk
  - Extreme events will also impact energy systems



1. The water – energy nexus

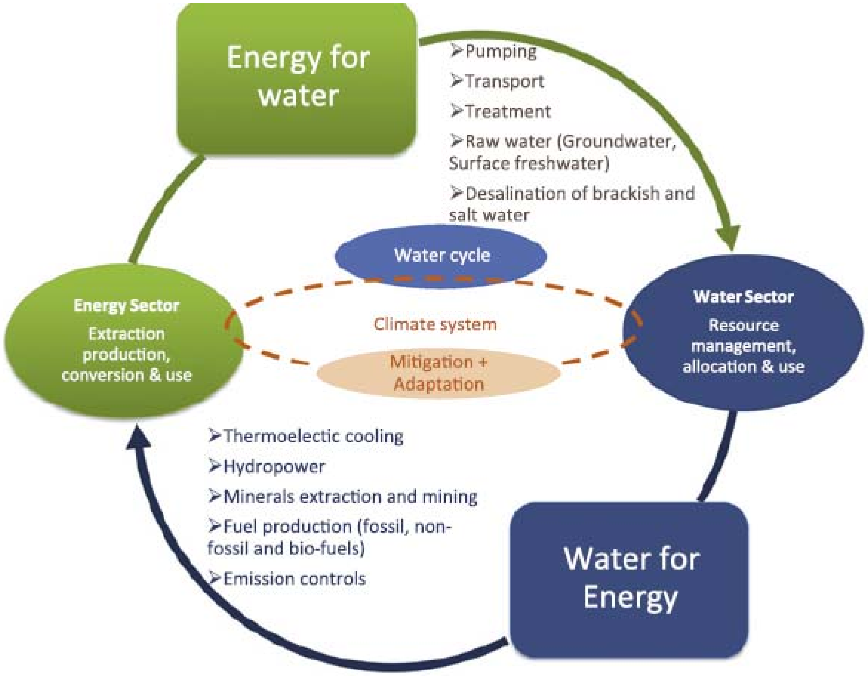
- The example of the 2003 heat wave in Europe and its impacts on the French energy system

> "Electricity demand increased but electricity production was undermined by the facts that the temperature of rivers rose, reducing the cooling efficiency of thermal power plants (conventional and nuclear) and that flows of rivers were diminished; six power plants were shut down completely (Létard et al., 2004). If the heat wave had continued, as much as 30% of national power production would have been at risk (Létard et al., 2004)."

Source: IPCC 4AR, Chapter 5

The water – energy nexus

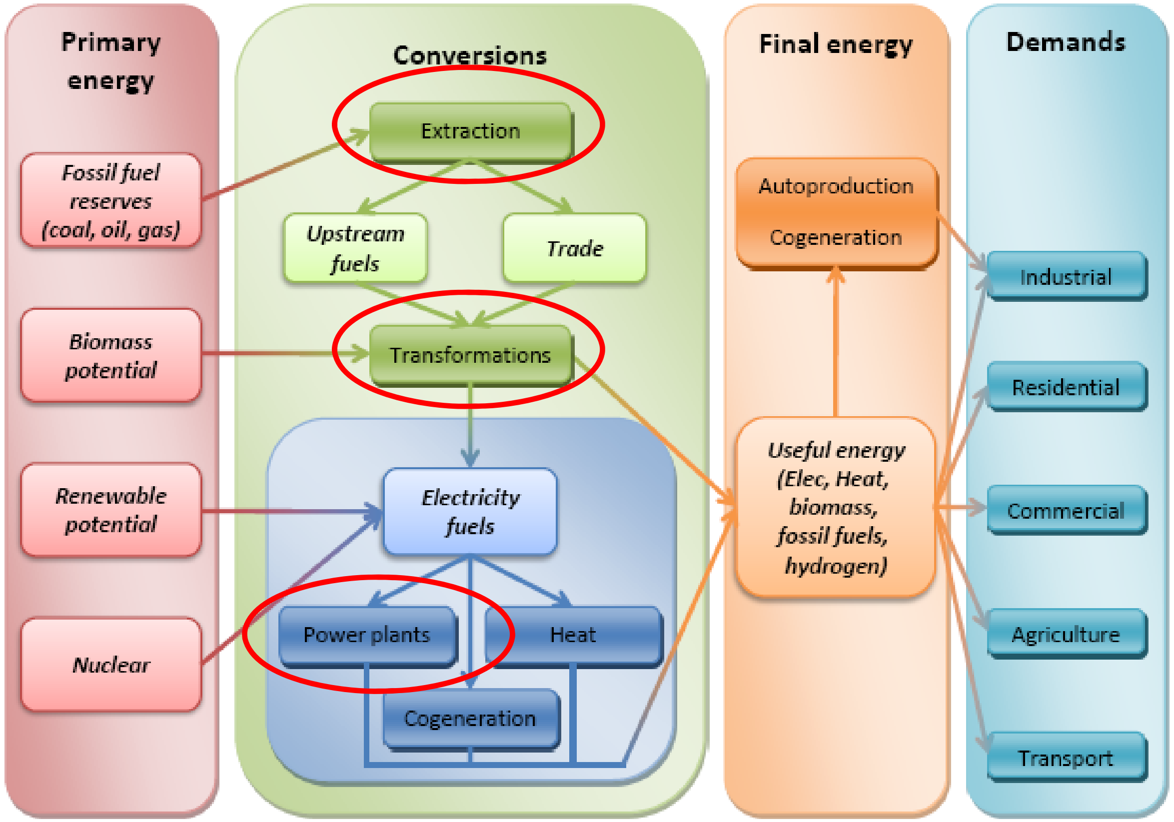
- Improvements in energy or water models are sought to improve our understanding of water and energy systems interactions



- Our approach is based on the coupling of a water model to the TIAM-FR energy optimization model

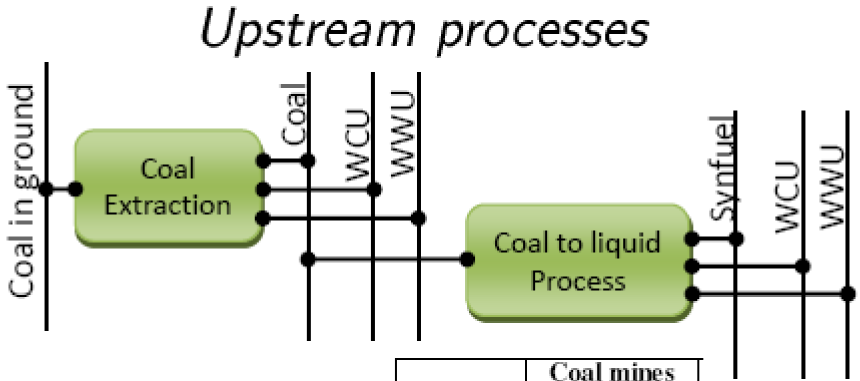
2. Modeling water requirements for energy production

- Water needs in an energy optimisation model



2. Modeling water requirements for energy production

- Upstream processes « water factors »

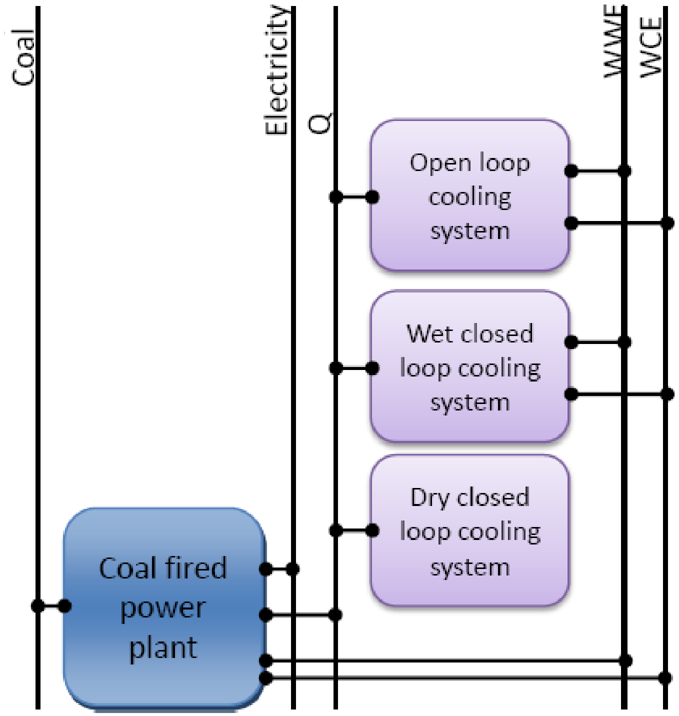


Upstream process	m^3/TJ
Coal extraction	
Mining	
Surface mining (S)	4[a]
Underground mining (U)	7[a]
Beneficiation	4

Regions	Coal mines S[a]	Coal mines U[b]
AFR	0.49	0.51
AUS	0.80	0.20
CAN	0.99	0.01
CHI*	0.10	0.90
CSA*	0.90	0.10
EEU*	0.69	0.31
FSU	0.46	0.54
IND*	0.85	0.15
JPN*	0.00	1.00
MEA*	0.31	0.69
MEX*	0.96	0.04
ODA*	0.99	0.01
SKO*	0.00	1.00
USA	0.67	0.33
WEU*	0.84	0.16

2. Modeling water requirements for energy production

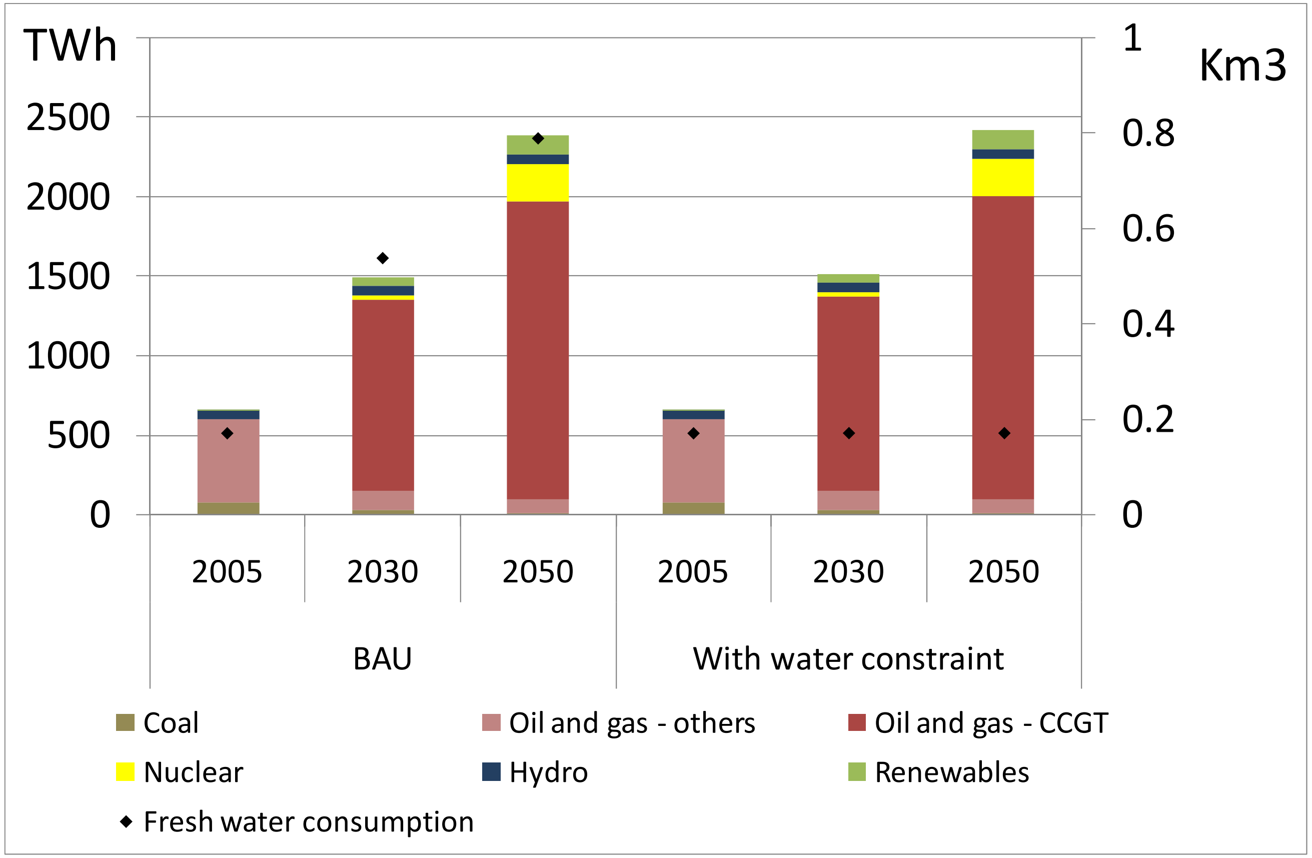
- Introducing flexible cooling systems for power plants



$$Q = \frac{1-\rho_{th}}{\rho_{th}} W_m$$

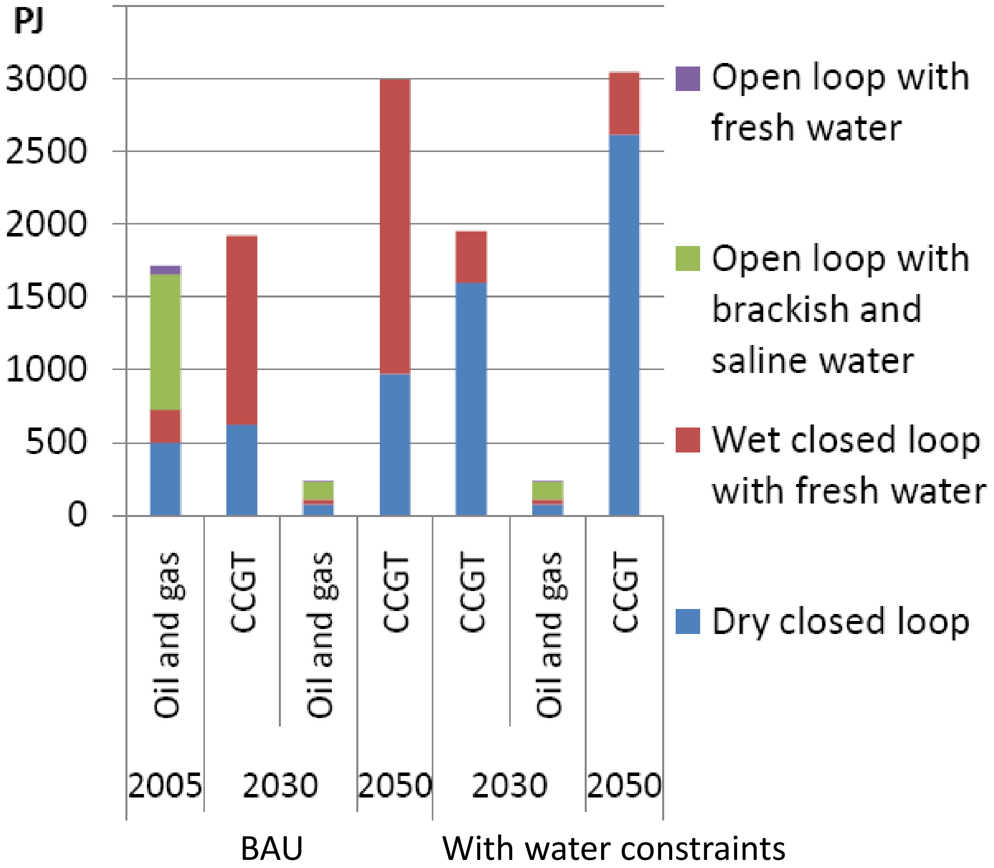
2. Modeling water requirements for energy production

- Power production under water constraints with TIAM-FR: Illustration for the MEA region



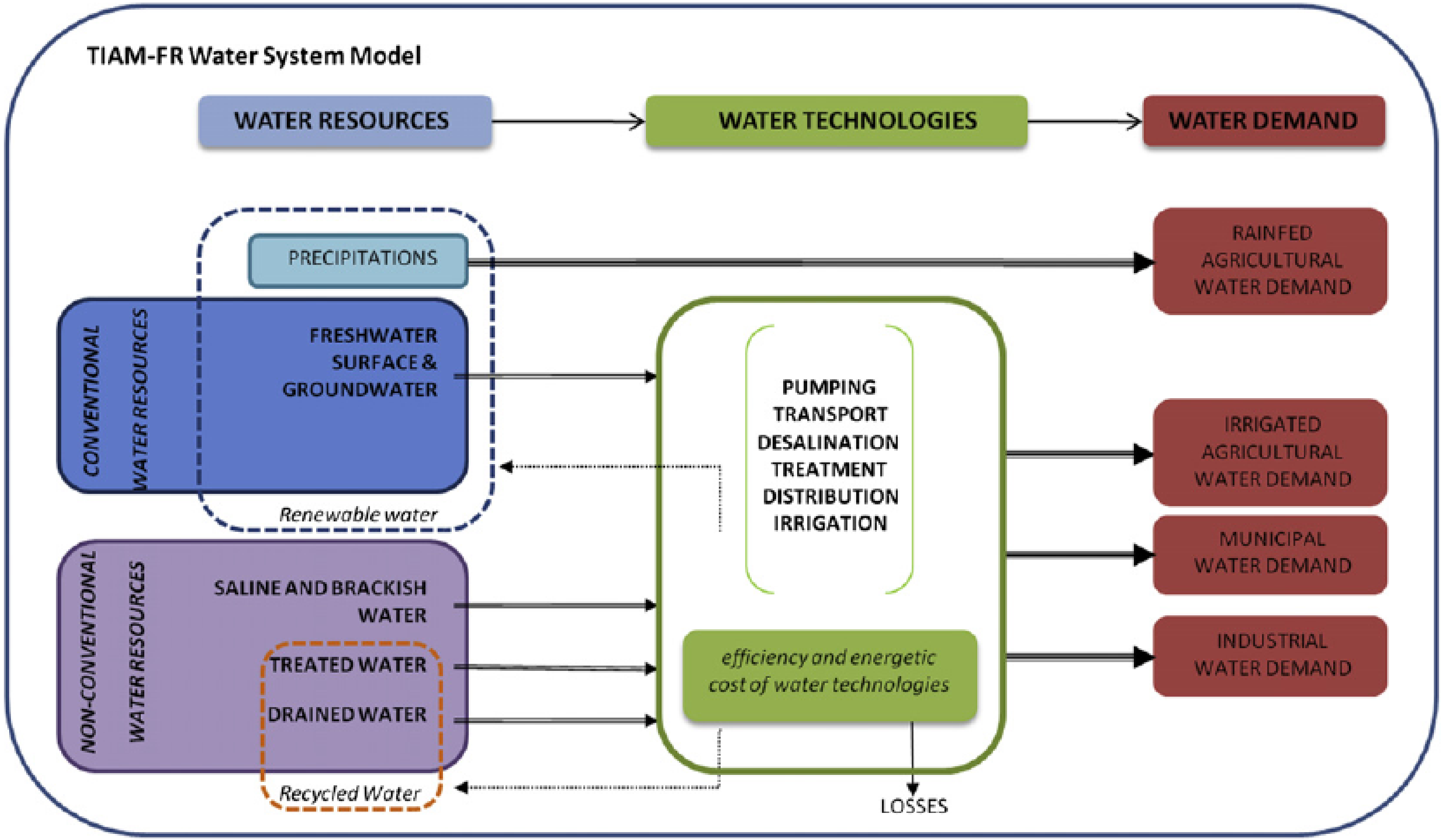
2. Modeling water requirements for energy production

- Power production under water constraints with TIAM-FR: Illustration for the MEA region



3. Modeling energy requirements for water supply

- Building a water allocation module

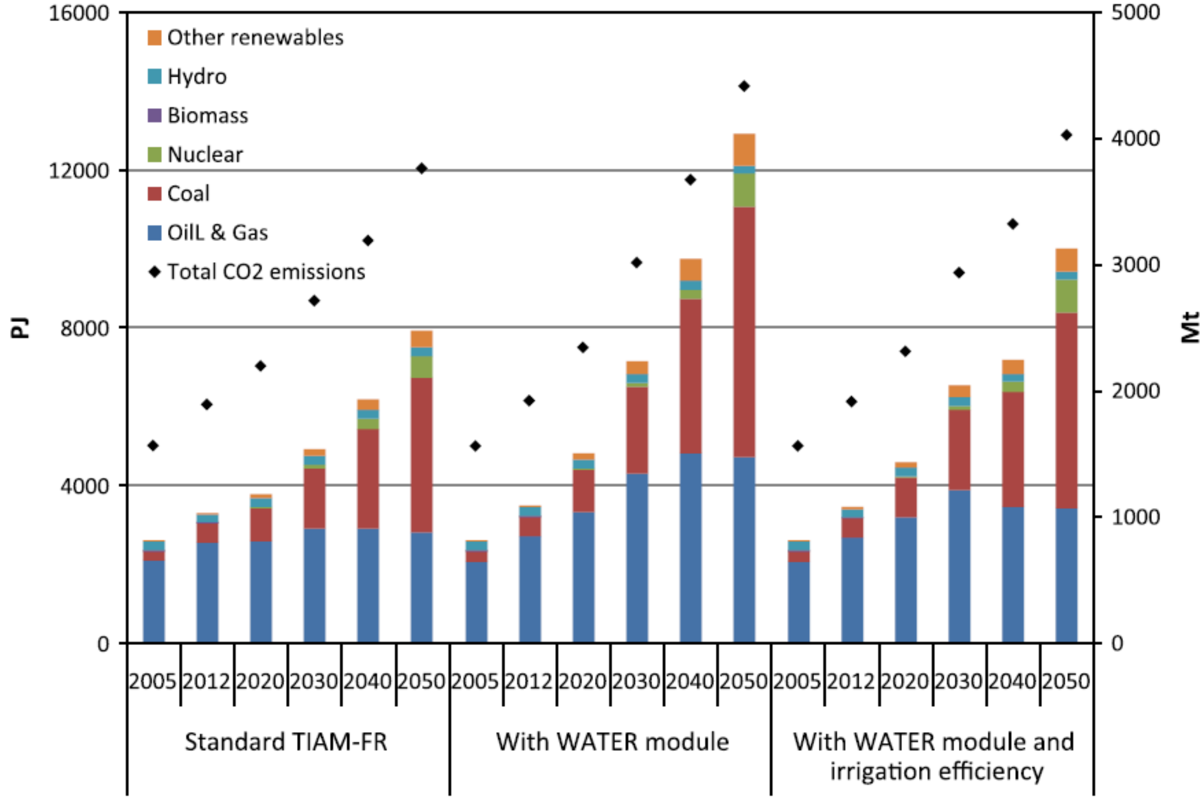


3. Modeling energy requirements for water supply

- Modeling water conservation measures: *useful resource per m3 input*
  - Rainfed agriculture: 0.6
  - Surface irrigated agriculture: 0.5
  - Sprinkler irrigated agriculture: 0.75
  - Localized irrigated agriculture: 0.8

3. Modeling energy requirements for water supply

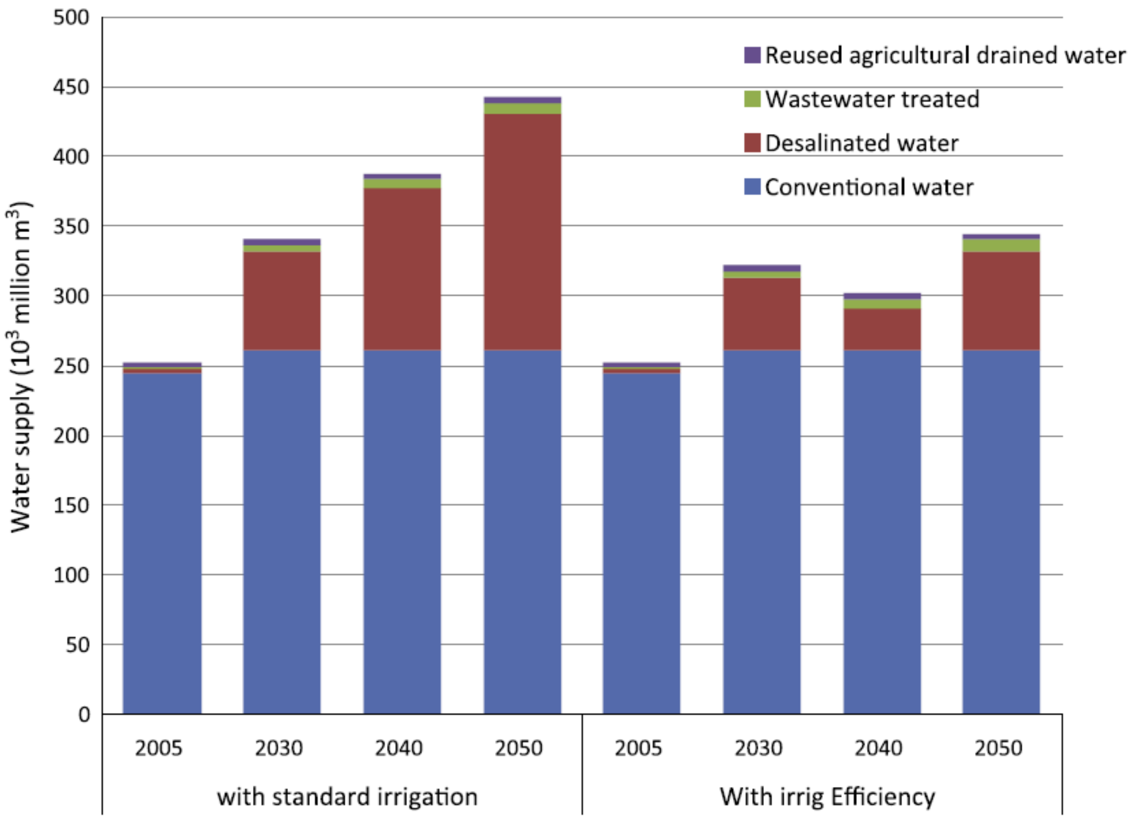
- Towards a better estimation of future energy demands: illustration for the MEA region



Efficient irrigation is an important electricity saving option (-22%)

3. Modeling energy requirements for water supply

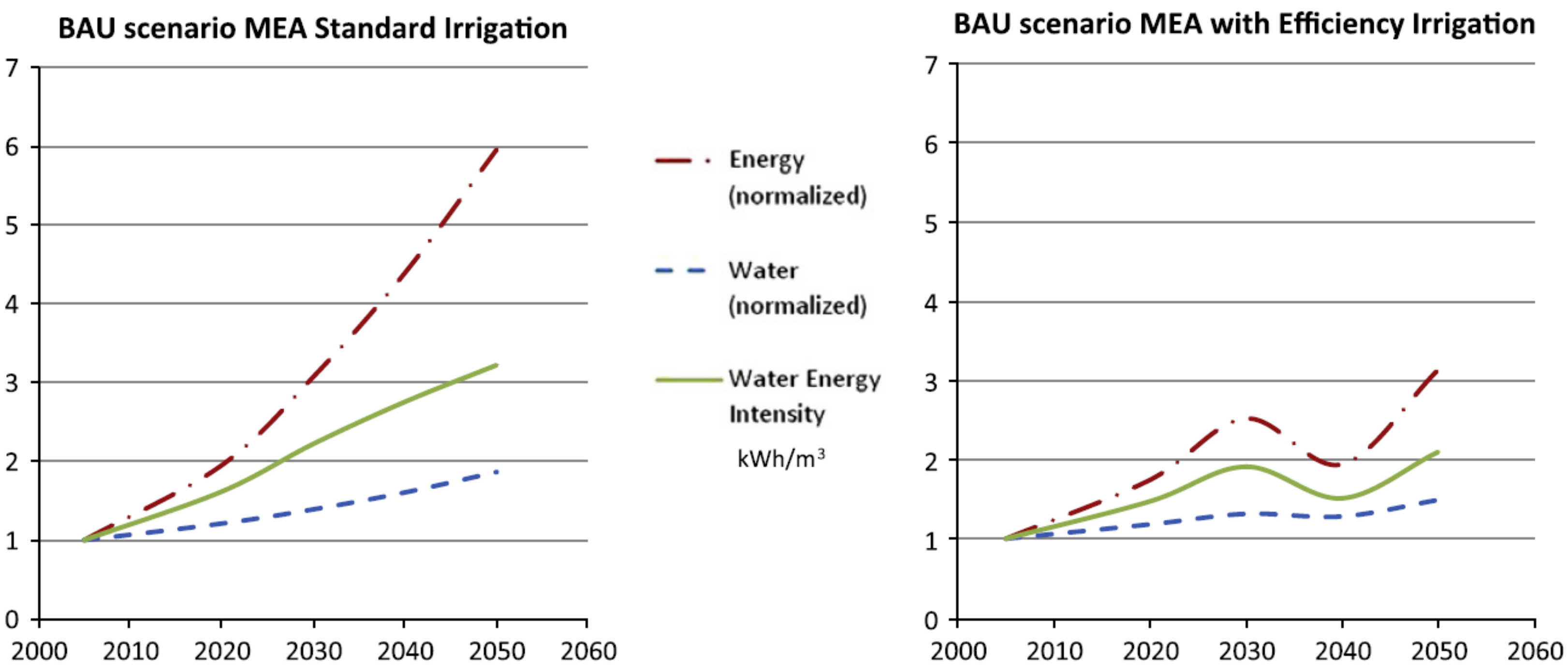
- Towards a better estimation of alternative water resources: illustration for the MEA region



Increased electricity use enables access to non conventional water resources

3. Modeling energy requirements for water supply

- Estimating the energy intensity and the substitution rate between water and energy



4. Conclusions

- The extended TIAM-FR model is a contribution to a better understanding of the structural links between energy and water systems. Under limited resource availability water management requirements impose new constraints on the design of energy systems
  - With current power plants designs, water consumption for electricity production is set to increase strongly with a growing electricity demand. However a simultaneous optimization of power plant and cooling technologies provides cost effective solutions for future power systems
  - In a water assessment perspective, conventional freshwater resources will not be sufficient to satisfy the demand in water scarce area such as the MEA. A smart water-energy nexus should hence combine water conservation measures and desalination. However efficient irrigation techniques will only partly compensate the increase in water-energy intensity.

1. The water – energy nexus

- IPCC projected evolutions with climate change: annual runoff

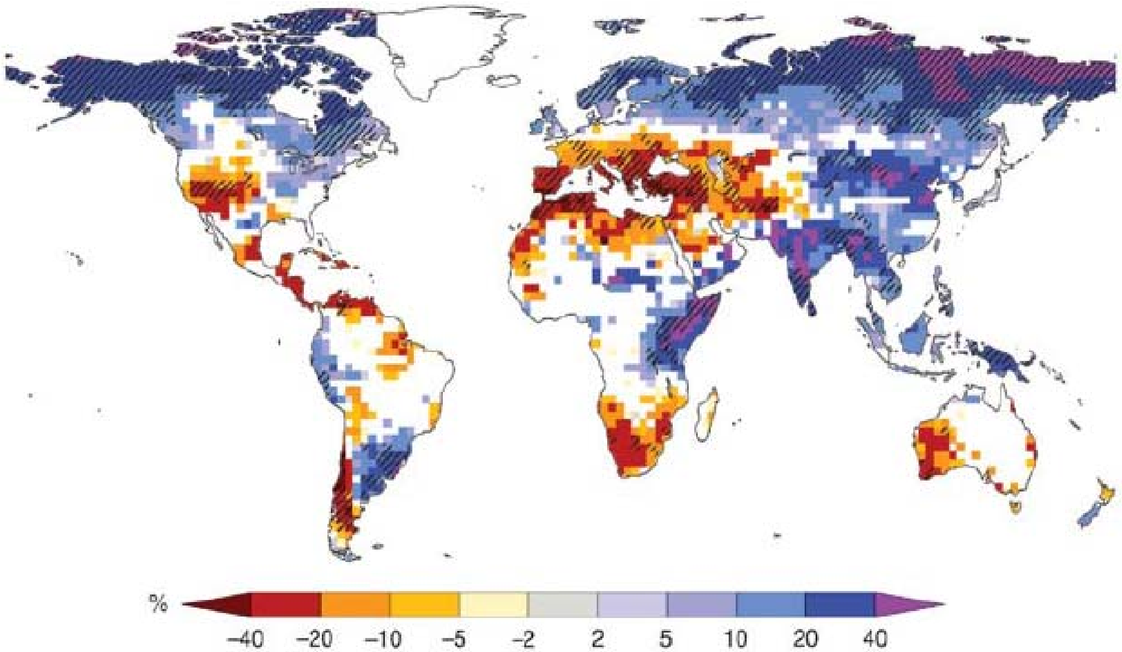
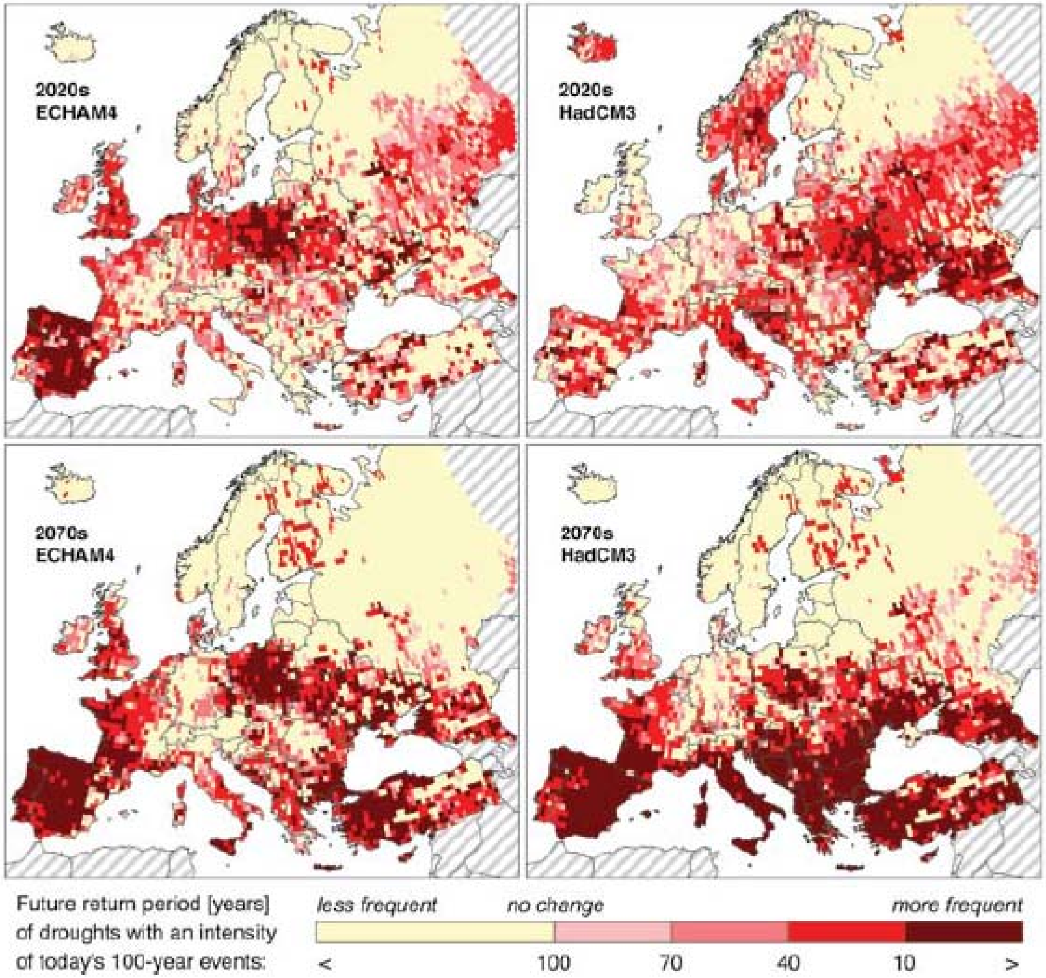


Figure 2.10: *Large-scale relative changes in annual runoff for the period 2090–2099, relative to 1980–1999. White areas are where less than 66% of the ensemble of 12 models agree on the sign of change, and hatched areas are where more than 90% of models agree on the sign of change (Milly et al., 2005). [Based on SYR Figure 3.5 and WGII Figure 3.4]*

1. The water – energy nexus

- IPCC projected evolutions with climate change: droughts



	Without CCS (m^3/MWh)	With CCS (m^3/MWh)
Subcritical PC	2.0	3.7
Supercritical PC	1.7	3.2
IGCC (slurry fed)	1.2	1.7
IGCC (dry fed)	1.1	1.8
NGCC	0.7	1.3
Nuclear	2.7	-

Source: World Energy Council 2010 from DOE 2008

Electricity Generation (TWh)	2005	2020	2035	2050
Total World	18,069	27,126	39,071	53,436
Thermal, of which :	12,126	18,461	24,782	31,638
Coal	7,235	9,679	12,601	17,766
Gas	3,478	6,746	8,908	9,840
Oil	1,102	995	983	1,185
Biomass and wastes	311	1,041	2,290	2,846
Nuclear	2,792	3,406	5,423	8,276
Hydro and geothermal	3,057	4,130	4,956	5,694
Wind and solar	94	1,129	3,910	7,827

Water Consumption (Bill. m^3)	2005	2020	2035	2050
Total World	41.1	56.4	75.9	100.2
Thermal, of which :	16.9	24.3	32.5	43.2
Coal	12.8	17.1	22.3	31.4
Gas	2.5	4.9	6.5	7.2
Oil	1.3	1.1	1.1	1.4
Biomass and wastes	0.4	1.2	2.6	3.3
Nuclear	7.6	9.3	14.8	22.6
Hydro and geothermal*	16.5	22.3	26.8	30.7
Wind and solar	0.0	0.5	1.9	3.7