Water-Energy Nexus: Impact on Electrical Energy Conversion and Mitigation by Smart Water Resources Management

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Water-Energy Nexus: Impact of Water Scarcity

- Water-energy nexus
  - Water is used in all stages of electrical energy generation
  - Electrical power is used for pumping, reprocessing and disposing of water

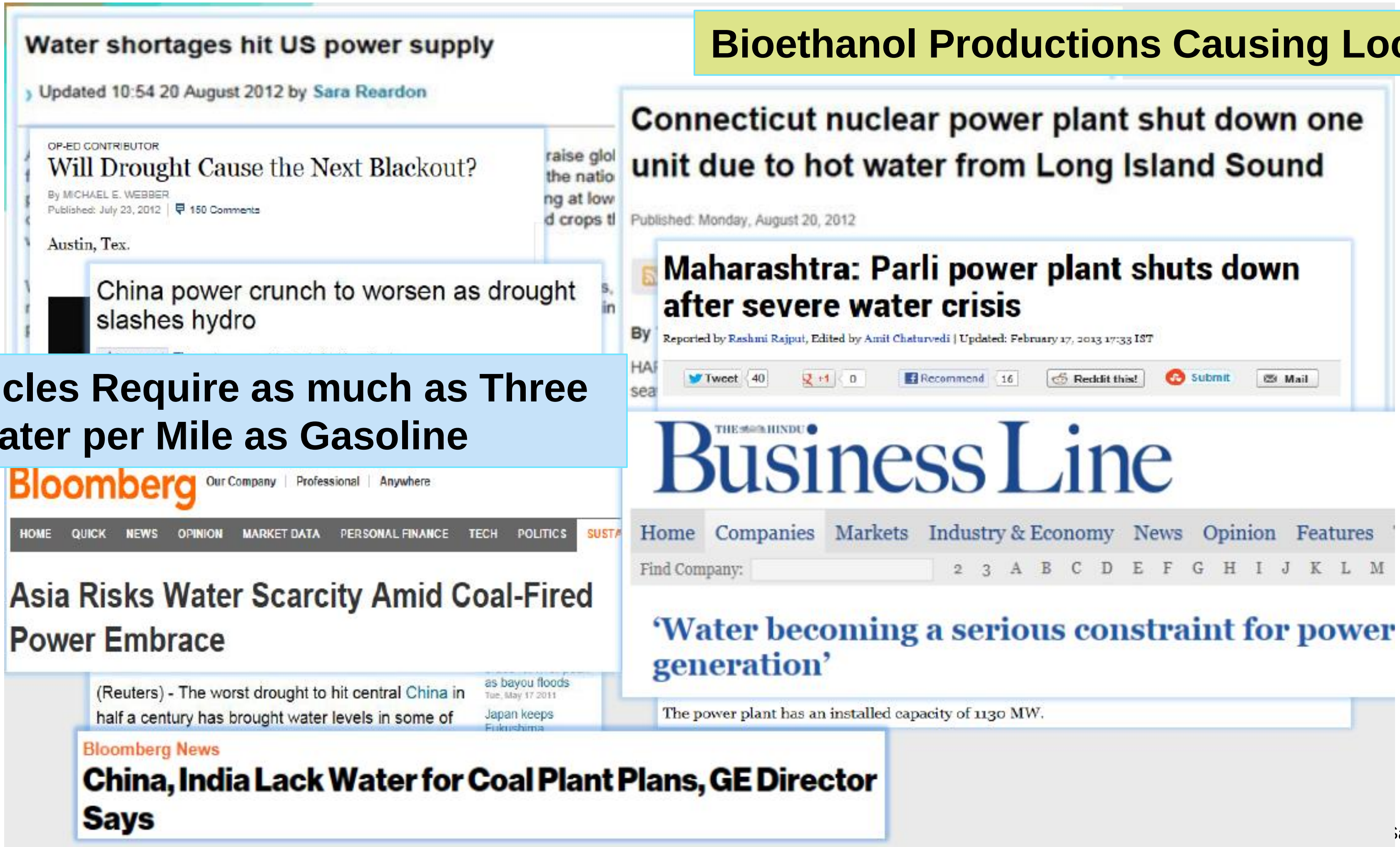
- Water scarcity and impact on power generation
  - Large loss of generation: USA (2007, 2008, 2012), France (2003, 2006, 2009), Germany (2003), Switzerland (2015)
  - Economic consequences
  - Reduced security of supply




Water-Energy Challenge – Policy Interdependency

Bioethanol Productions Causing Local Droughts

Electric Vehicles Require as much as Three Times the Water per Mile as Gasoline

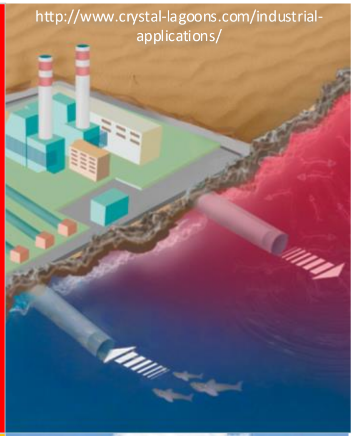


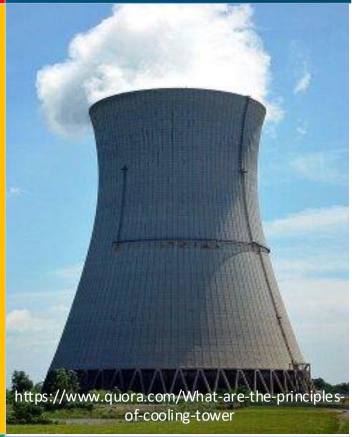
Outline

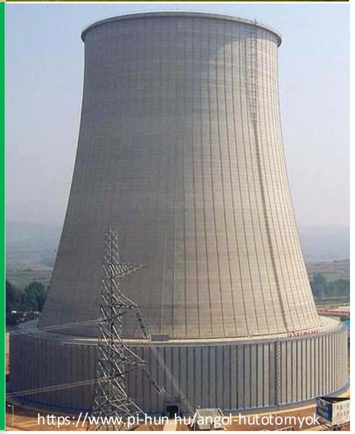
- Water-Energy Nexus: impact of water scarcity
- Technologies and policies for thermal power plant cooling
- Smart management of water resources
- Interplay between policy constraints and cooling technologies
- Conclusions and future work

Cooling technologies for thermal power plants

- Once-through cooling
  - Efficient, simple, lower costs
  - Large withdrawals, effecting river water thermal regimes
- Wet-type cooling towers
  - Does not requires large withdrawals
  - Consumes the withdrawn water
- Dry cooling towers
  - Does not require water for cooling
  - Higher costs, large space, lower efficiency

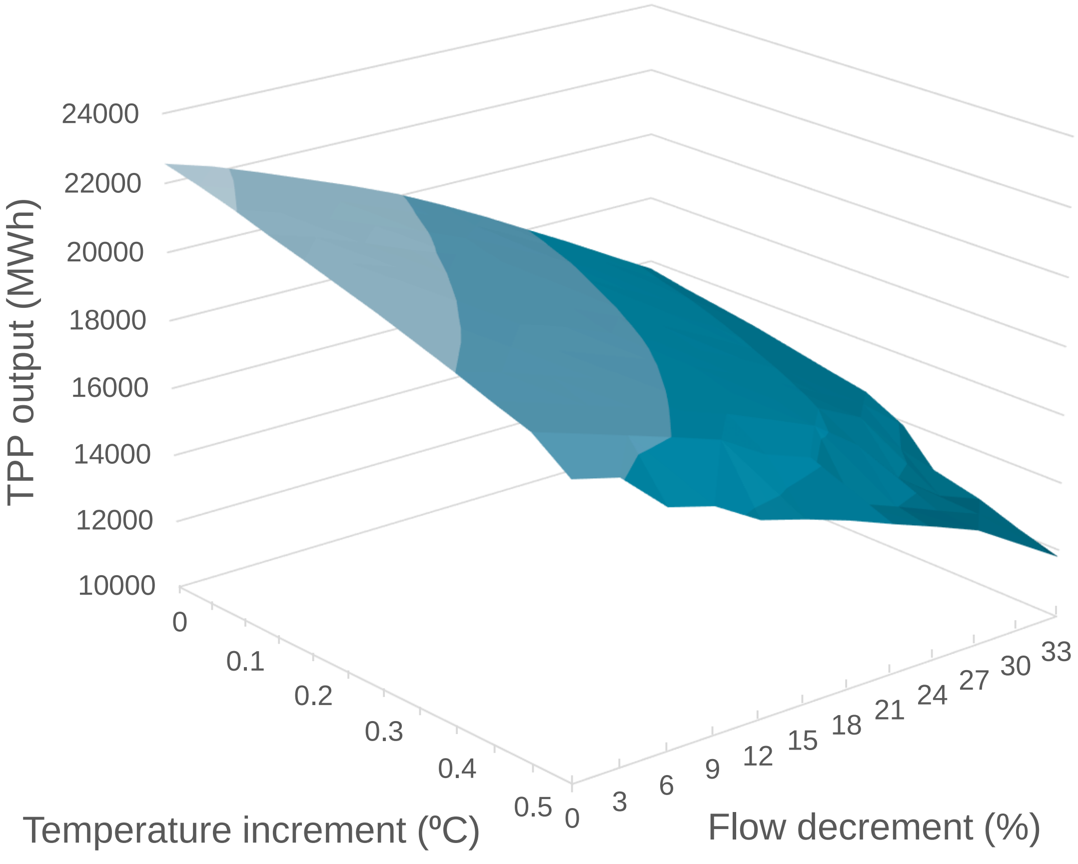






Policies for thermal power plant cooling

- River wildlife protection
  - Release of thermal load
- River temperature constraints
  - Salmonid waters
    - $T_{max} \leq 21.5\ ^0\mathrm{C}$
    - $\Delta T \leq 1.5\ ^0\mathrm{C}$
- Water withdrawal and consumption
  - Based on local river concessioners
  - Consumption constraint to: 1% of current flow



1000MW TPP with once-trough cooling

Mitigating the vulnerabilities of water-energy nexus for thermal power plant cooling

- Can we influence river water temperature and flow?
  - Yes!
- How?
  - By manipulating reservoir releases
- A model for smart scheduling of water resources
  - Hydro generation model
  - Thermal generation model
  - River water temperature prediction
  - Mixing of river flows

Smart scheduling of water resources

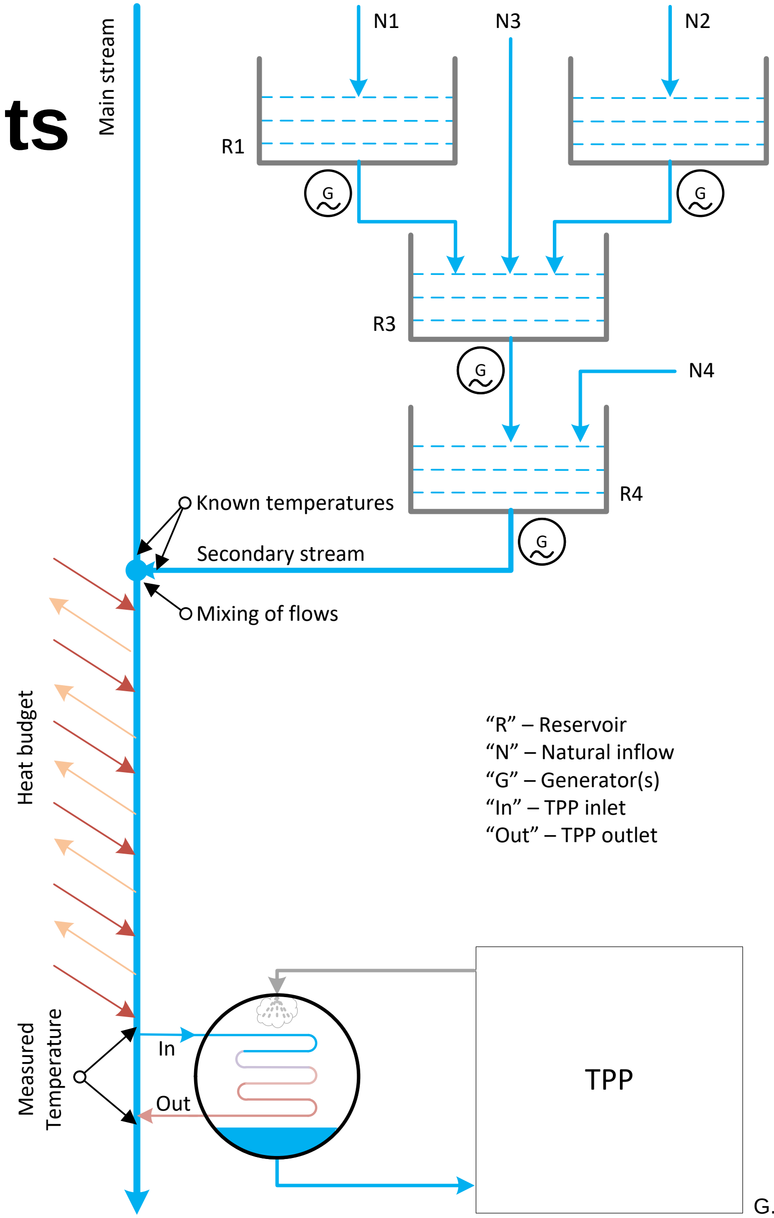
- A model for smart scheduling of water resources
  - Hydro generation model
    $P_{H_{j,t}} = C_{1,j} * V_{j,t}{}^2 + C_{2,j} * X_{j,t}{}^2 + C_{3,j} * V_{j,t} * X_{j,t} + C_{4,j} * V_{j,t} + C_{5,j} * X_{j,t} + C_{6,i}$
  - Mixing of river flows
    - $T_{river}^{mix} = \frac{(T_{str1} * Q_{str1}) + (T_{str2} * Q_{str2})}{Q_{str1} + Q_{str2}}$
  - River water temperature prediction
    - $\frac{\partial T}{\partial t} + v * \frac{\partial T}{\partial x} = \frac{1}{A} * \frac{\partial}{\partial t}\left(A * D_L * \frac{\partial T}{\partial x}\right) + \frac{R_W}{\rho * c_p * A} * S$
  - Thermal generation model
    - $T_{out}^{river} = \frac{P_{thermal}^{TPP}}{Q * \rho * c_p} + T_{in}^{river}$

Hydraulically coupled power plants

- Test system with a hydro cascade
  - A cascade of four HPPs

  - Thermal power plant
    - 1000 MW
    - Minimum output of 30%
    - Once-trough cooling

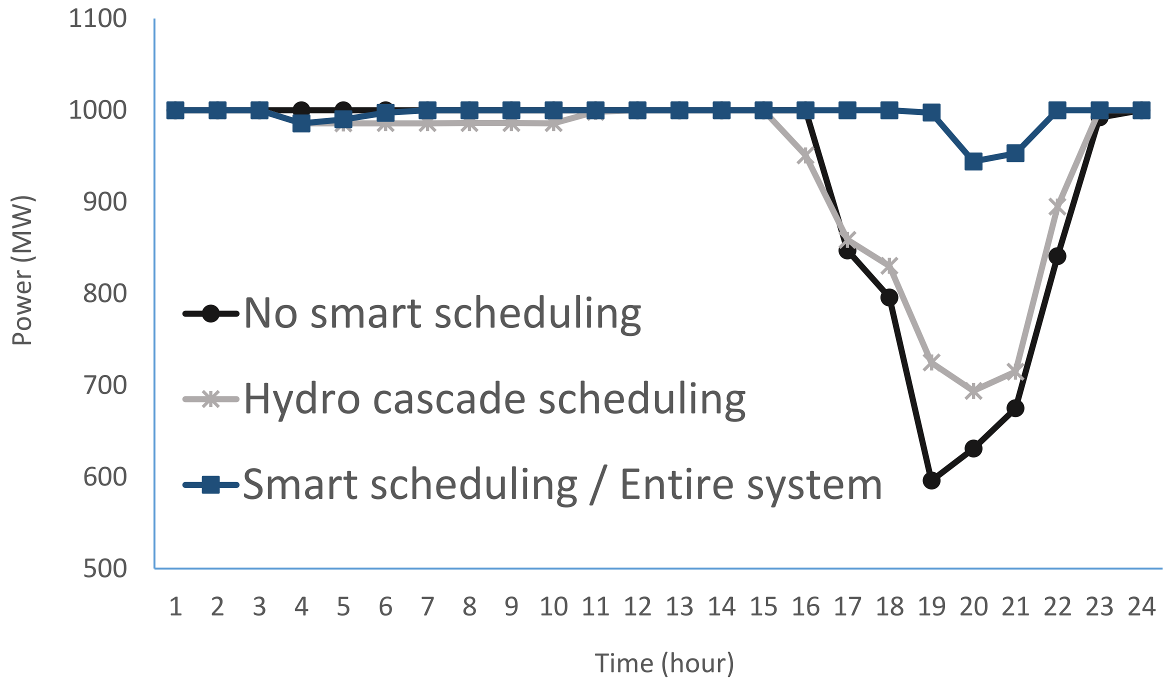
  - Data based on Switzerland
    - Aar rive basin hydrology/meteorology
    - Swiss electricity prices



Gjorgiev and Sansavini, Energy Conversion and Management, 2017

Smart management of water resources for improved power generation

- Apply the model for smart scheduling
- Results: Energy maximization
  - Energy increase
    - 2.75 % to 6.37 %
- Results: Revenue maximization
  - Revenues increase
    - 3.60 % to 7.41 %
- Strong interdependence
  - 1.5 ^{0}C increase in water temperature (when near allowed water temperature constraints) can result in ~ 50% power output reduction, and in extreme cases, in plant shut down



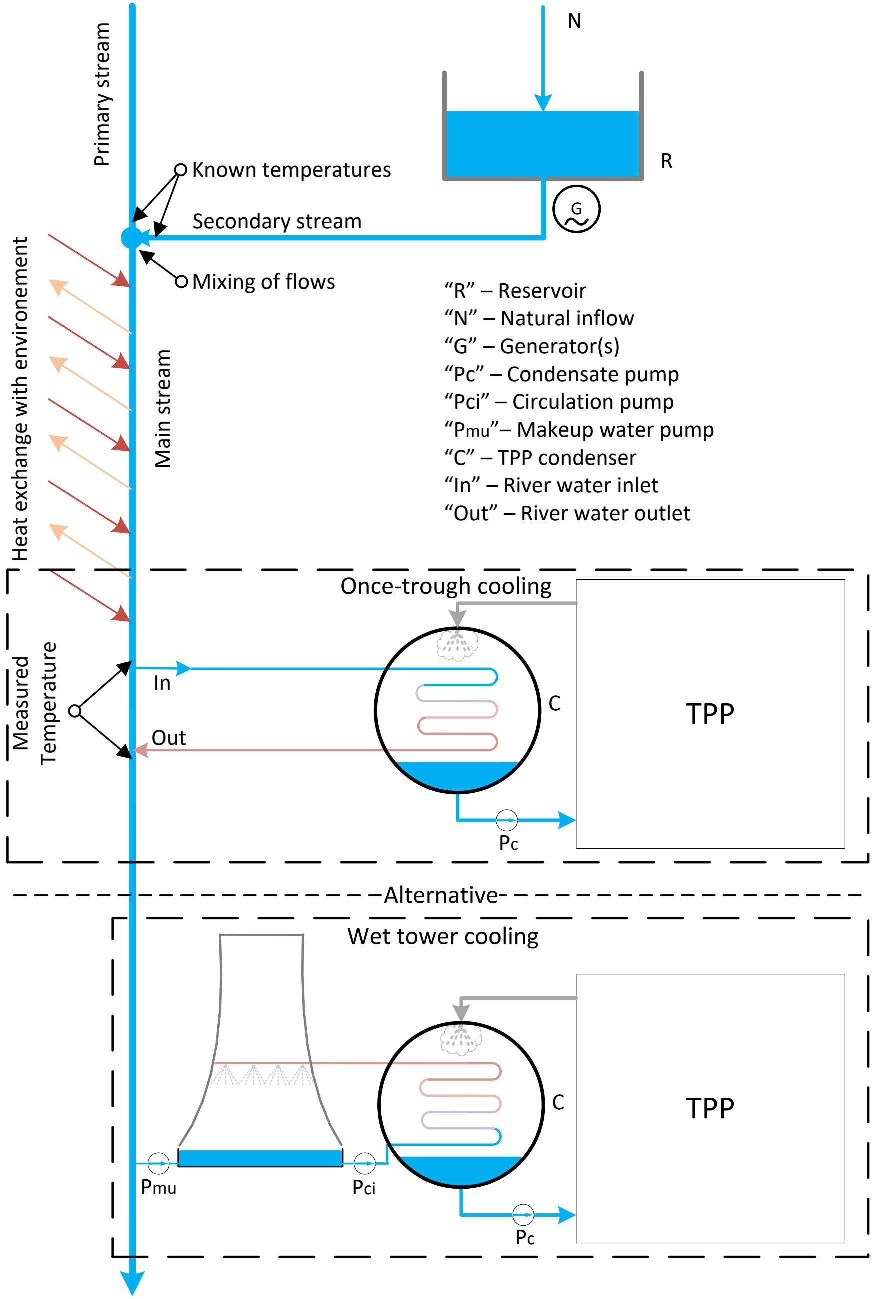
Electric power outputs of the TPP

Water policy constraints and cooling technologies

- Assess how plant output is effected by the flexibility of the water temperature constraints
  - Simulation of drought conditions
  - Allow constrained relaxations
  - Smart management

- Different cooling technologies
  - Once-trough cooling
  - Wet type cooling tower

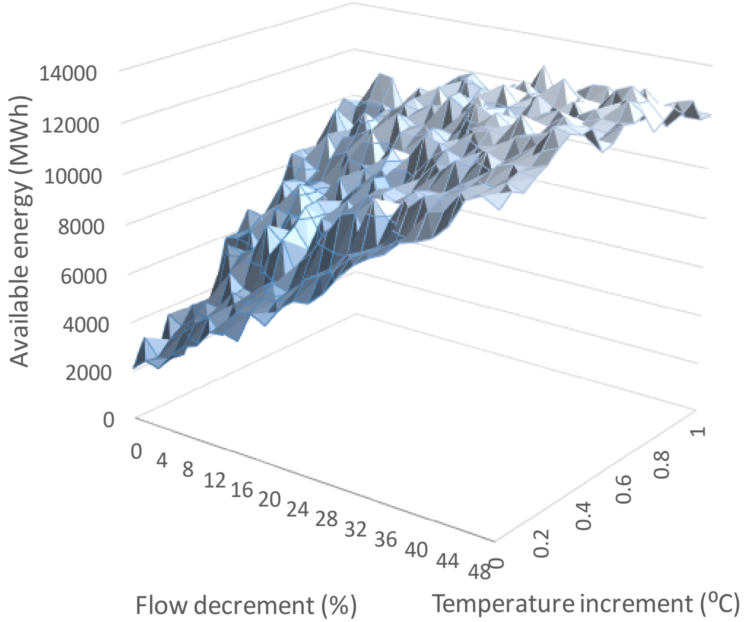
- Considered water policy constraints
  - Water temperature
  - Water withdrawal and consumption



Gjorgiev and Sansavini, Applied Energy, 2018

Relaxation of water policies: impact on power generation

- Once-trough cooling
  - No smart water management
  - Water temperature constraint relaxations
- Relaxation of 1.5 °C in the water policy constraints prevents the curtailment of 42%



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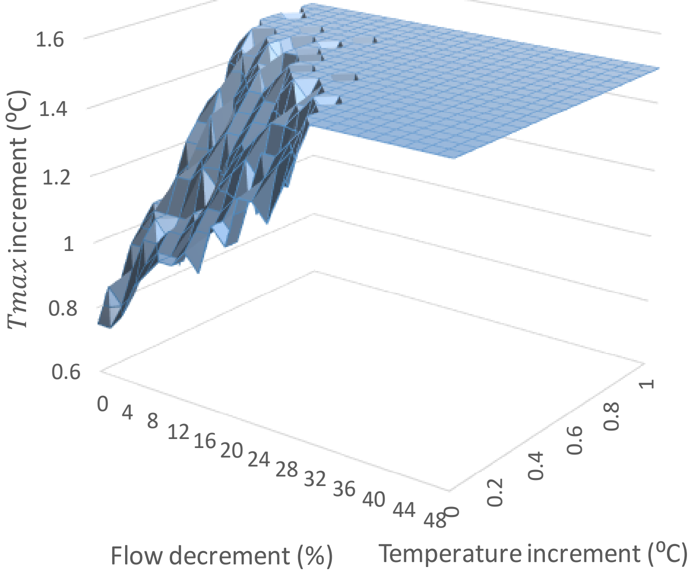

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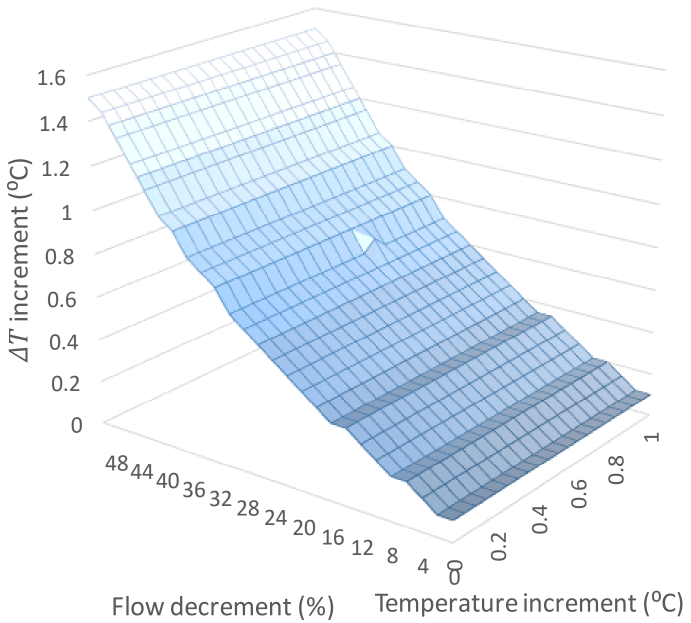

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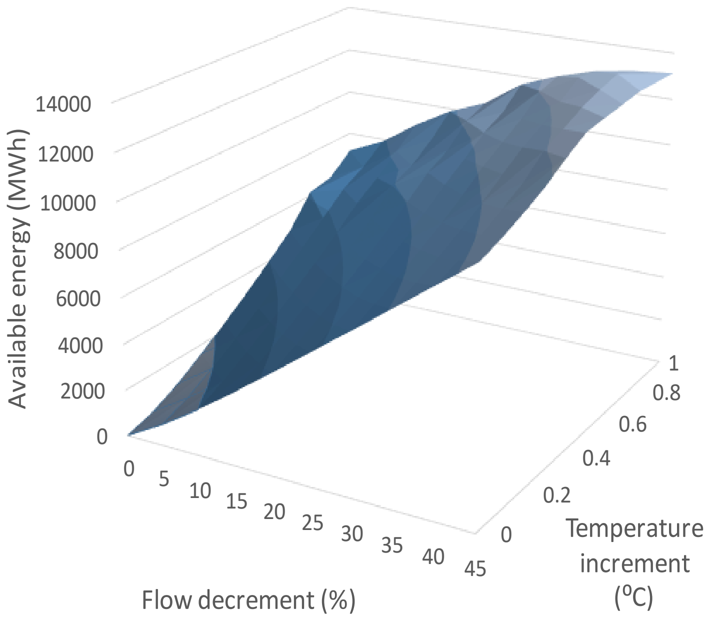
Relaxation of water policies: impact on power generation

- Once-trough cooling
  - Smart water management
  - Water temperature constraint relaxations

- Compared to the un-optimized case
  - At least 7% increase in the converted energy
  - For most drought scenarios much less relaxation than maximum allowed 1.5 °C is needed
  - Stable thermal power plant outputs



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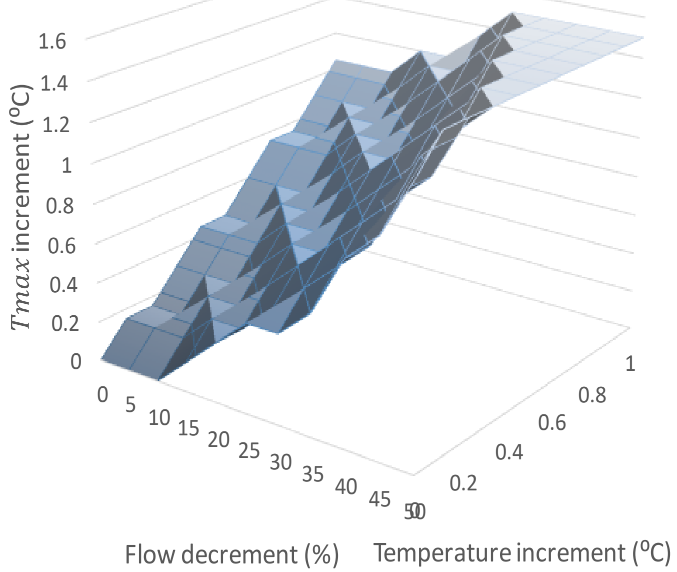

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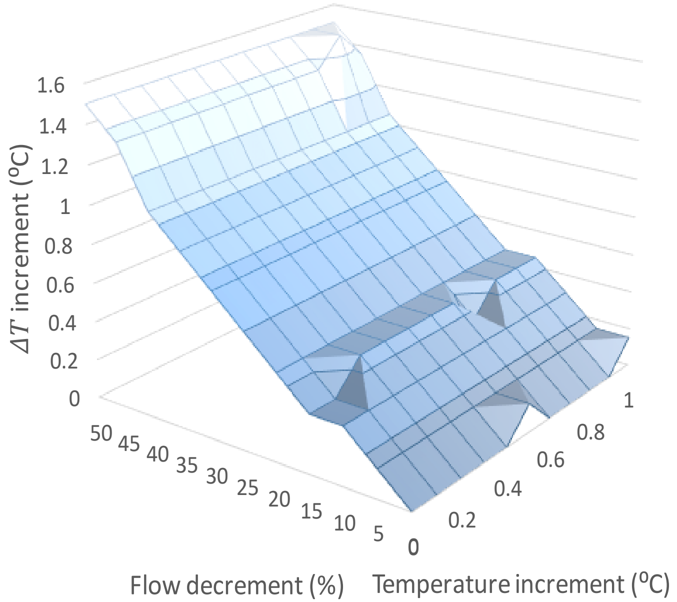

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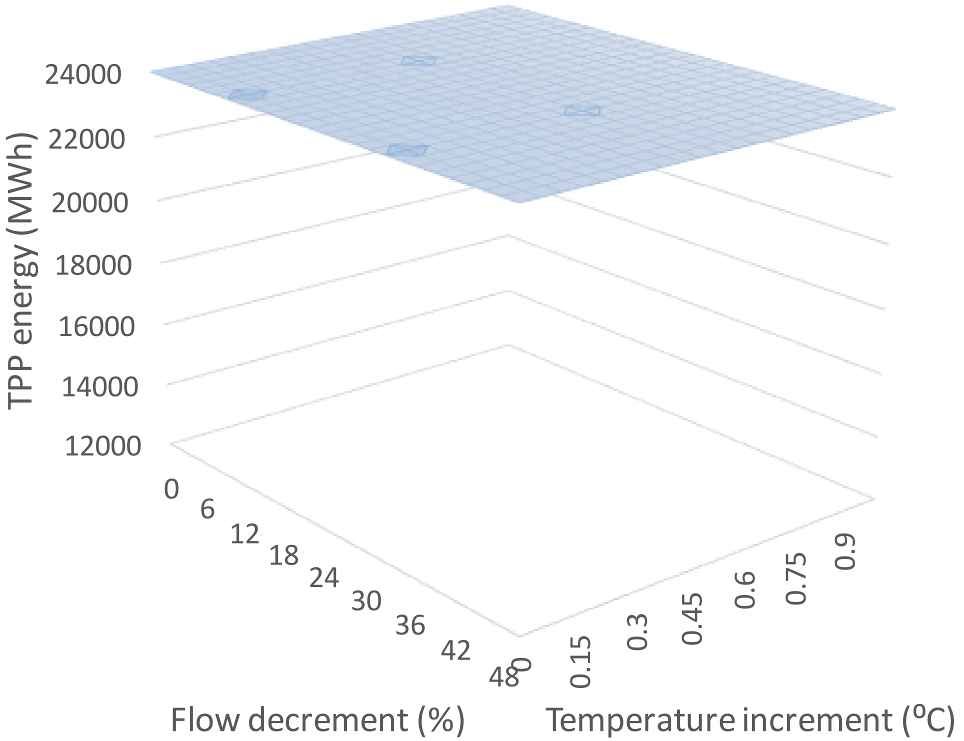
Water policy constraints relaxation effect on power generation

- Wet type cooling tower
  - No power generation reduction required

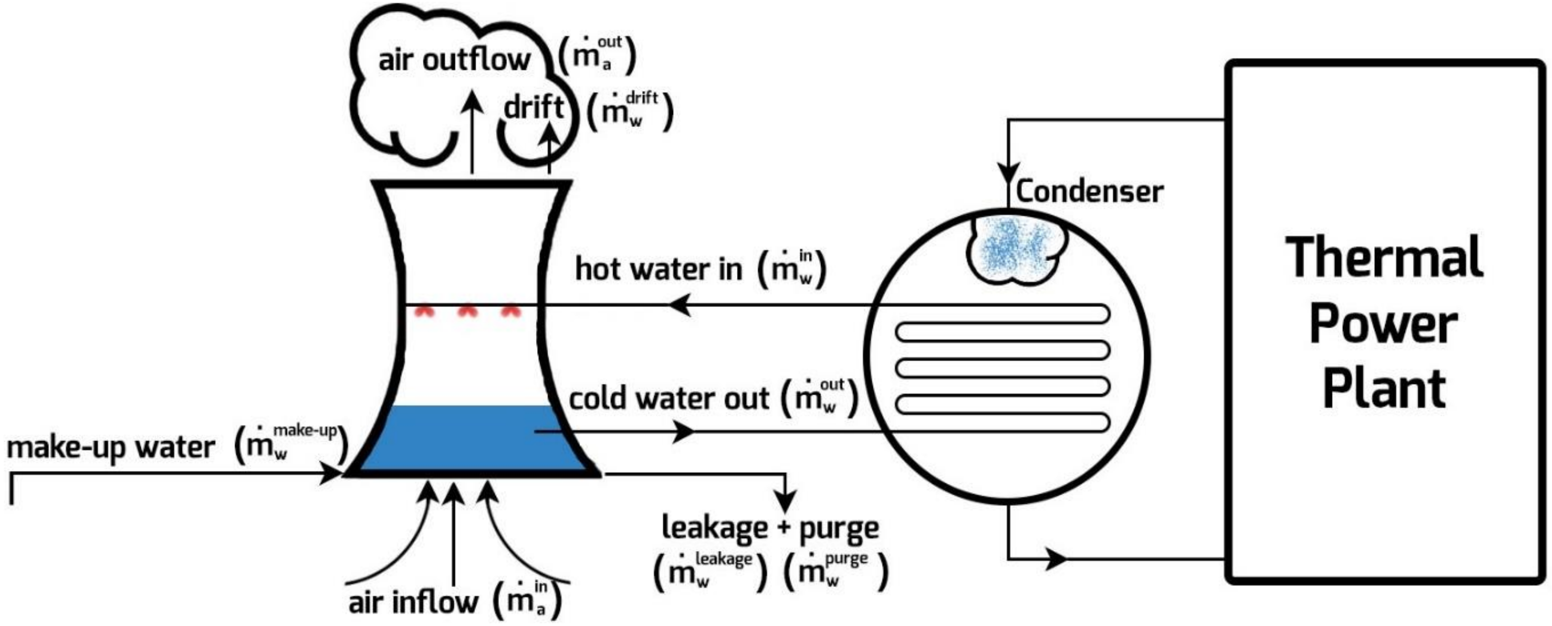
- Recommendations
  - Use location specific characteristics for drought scenarios
    - River specifics
    - Long-term climate change prognosis
      - River water temperature and flow
      - Air temperature

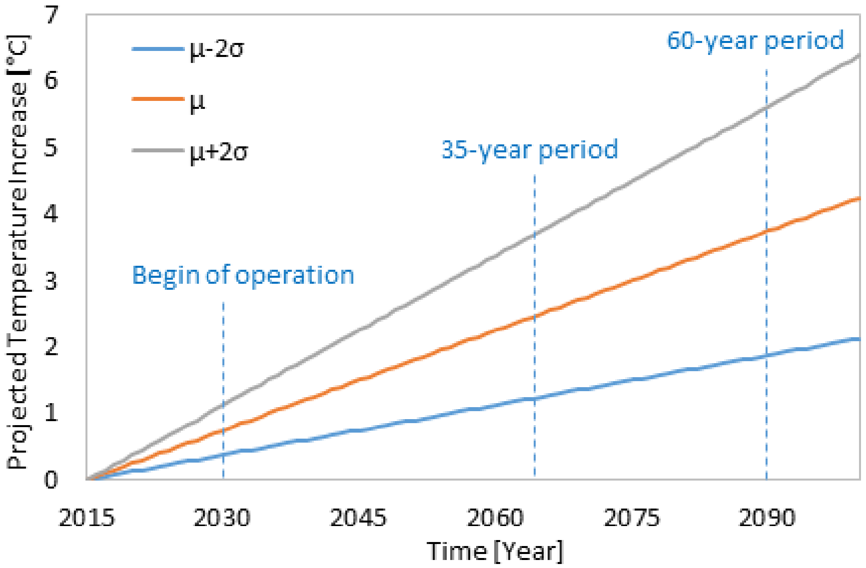


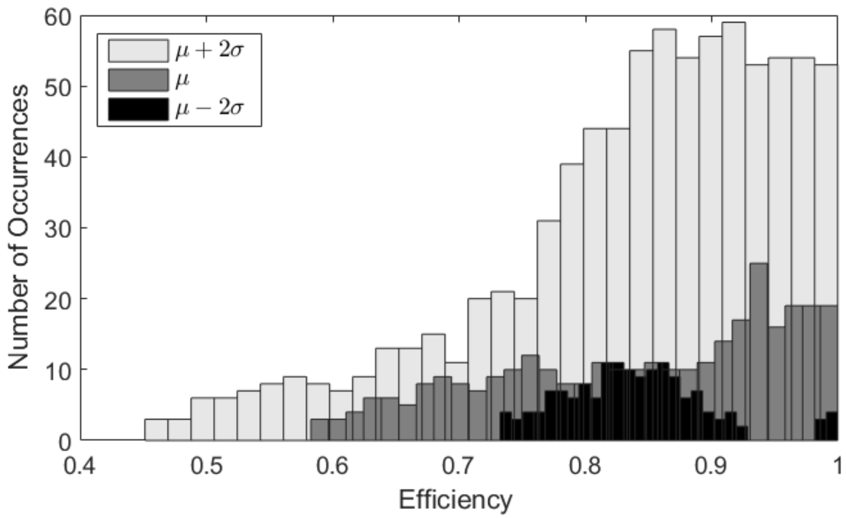
Electrical energy conversion under different drought scenarios

Wet tower cooling and climate change

- Wet cooling tower model
  - Input
    - Air temperature
    - Air moisture
    - Water temperature
  - Output
    - Tower efficiency
    - Power plant output
- Climate change
  - Long-term effect
  - Optimal tower height







Ayoub, Gjorgiev and Sansavini, Energy, under review

Conclusion and Future work

- Smart water management via co-optimization of energy and water resources can improve generation during droughts

- Constraint relaxation can significantly improve power generation but other constraints need to be considered also, i.e., ecology, hydro- and thermo-peaking, hydropower market

- Once-trough cooling highly sensitive to water temperature changes

  Wet-cooling towers more resilient to water temperature changes

- Need for systemic power system reliability analyses with droughts
  - Generation availability
  - Security of supply

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Thank you!
Questions?