Future DAMS

Design and Assessment of water-energy-food-environment Mega-Systems

MANCHESTER 1824

The University of Manchester

Assessment of soft and hard linking approaches of integrated water-energy simulation

Presenter: Mikiyas Etichia

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Presentation outline

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- Item 1 Introduction
- Item 2 Research objective
- Item 3 Integrated water-energy simulator
- Item 4 Formulation of the linking approaches
- Item 5 Case study
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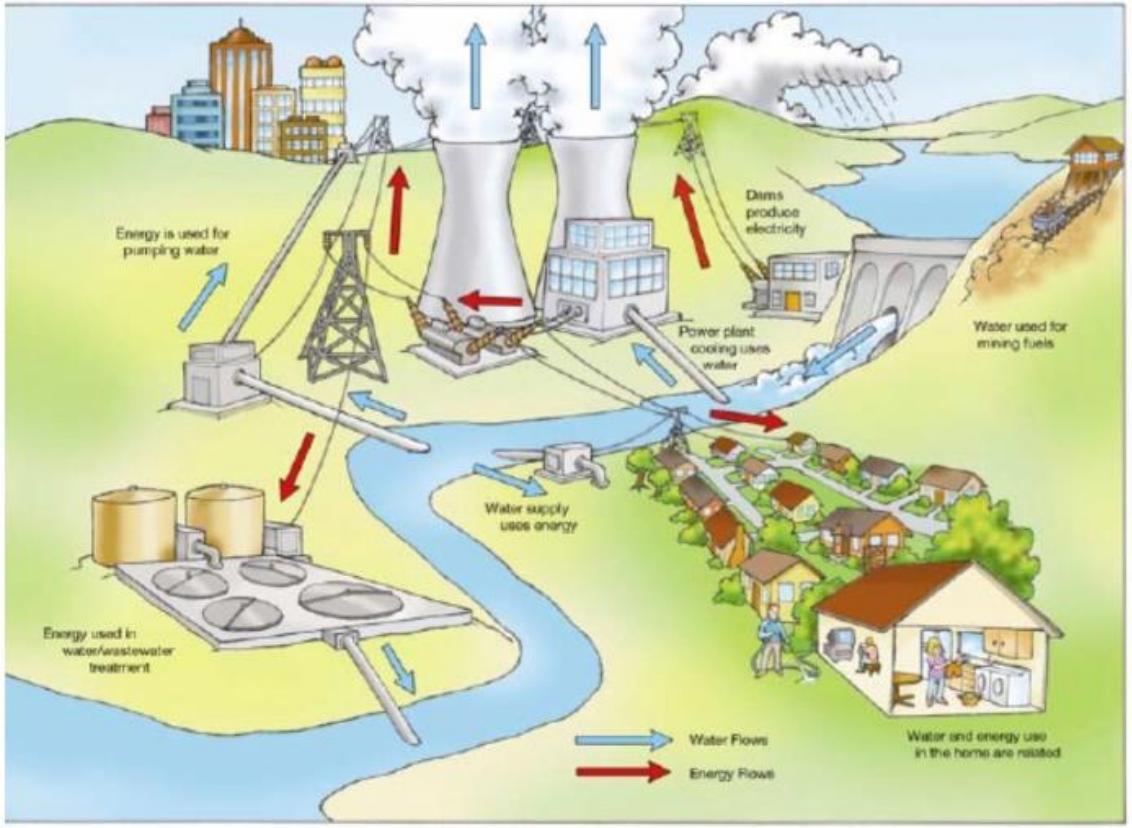
- Item 7 Conclusion

1- Introduction

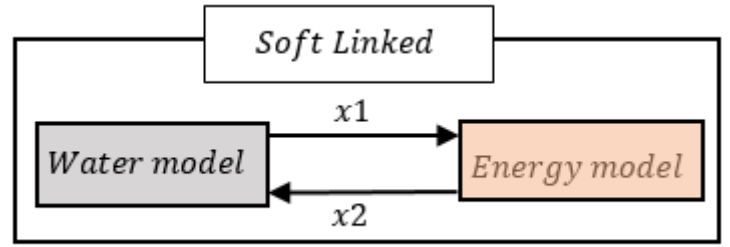
- **Water and energy system are interlinked**
- **Benefits** to be gained from **integrated resource operation** will be key to improving resource utilization efficiencies
- Advances in **operational modelling approaches** that capture synergies between water-energy systems are indispensable

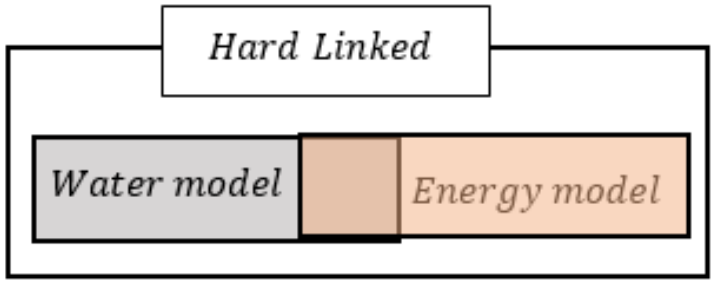


Source: U.S. Department of Energy, Energy Demands on Water Resource, Report to Congress on the Interdependency of Energy and Water, December 2006, p. 13.

1- Introduction

- Existing **approaches to coupling water and energy models** can be grouped in in two main categories:
  - **Soft-linked approaches**: water and energy models operate independent of one another but **pass data back and forth** to reach convergence or run sequentially to conduct a defined number of iteration.
  - **Hard-linked approaches**: the two models combined into a **single mathematical programming** formulation which can be solved in a **simultaneous optimization**.
- The **advantages and disadvantages** of the water and energy **model coupling approaches** is not explored from:
  - Water and energy resource allocation
  - Computational cost
  - Flexibility and scalability

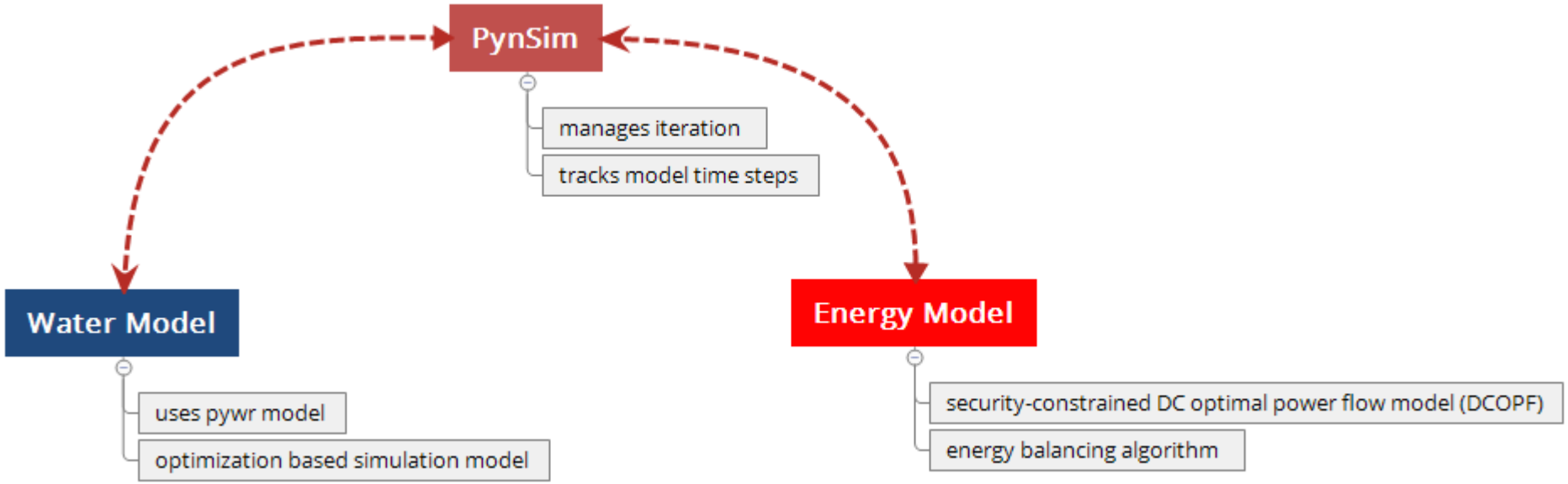




2- Research Objectives

- Creating soft linking formulation
- Creating hard linking formulation
- Applying on a pragmatic case study
- Comparing the advantage and disadvantage two linking approaches

3- Water-energy simulation



- The water system is modelled using pywr model (Tomlinson, Arnott, & Harou, 2020)
- The energy system is a security-constrained DC optimal power flow model (DCOPF)
- The water and energy models linked using pynsim (Knox, Meier, Yoon, & Harou, 2018)
- Water and energy models linked through hydropower

4- Formulation of soft linking approach

- Two model setups categories under the soft linking approaches:
  - One-way communication (Fig A)
  - Two-way communication (Fig B)

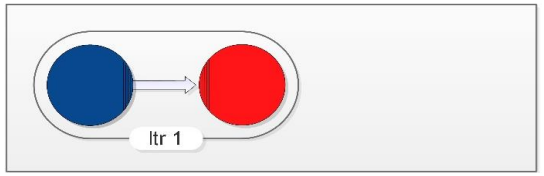


Figure A) One-way water energy communication

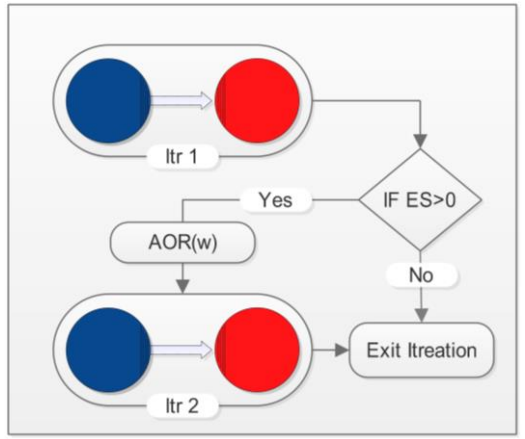


Figure B) Two-way water energy communication

$$AOR\left(rn_{t,itr2}\right) = Q_{n,t,itr1} - \frac{ES_{t,itr1}}{g\rho\eta h_{net,itr1}} \qquad if \quad ES_t \geq 0$$

4- Formulation of hard linking approach

- The water and energy models share **a common objective function** of minimizing the total cost of energy generation and water allocation

- From the energy model perspective, the most cost-effective solution is to **use all hydropower** available in the current time step **with no regard for future time steps**

- **Reservoir scarcity cost curve** is introduced in this study to balance the trade-offs between the water and energy objectives

- In between the h_{max} and h_{min}, the scarcity cost of stored water levels could be derived

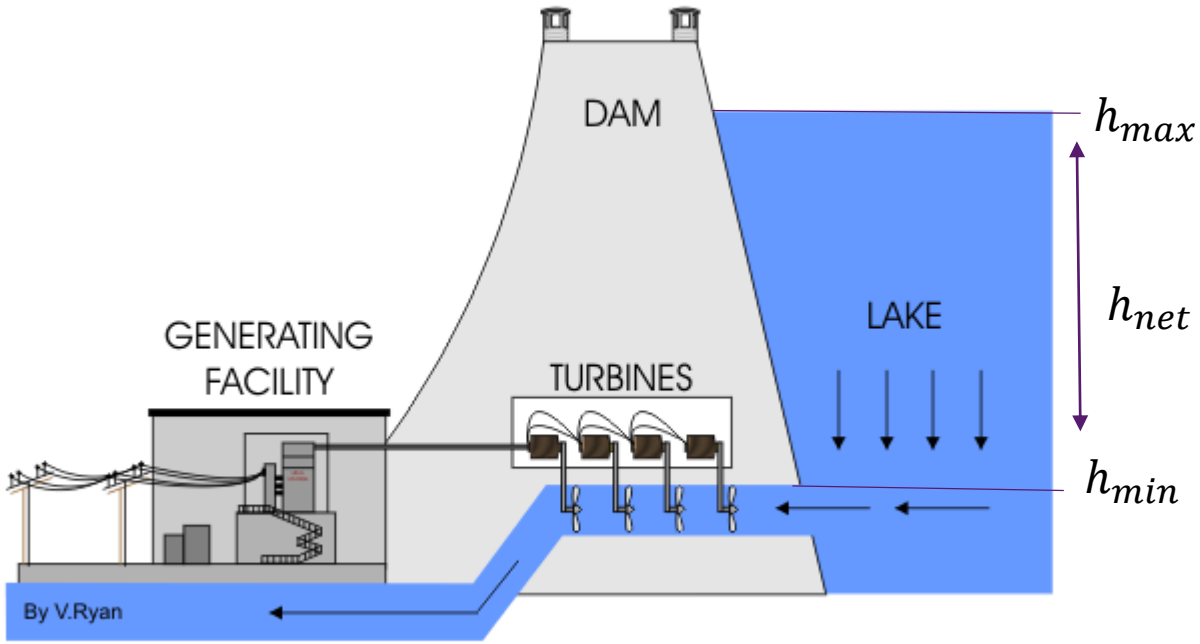
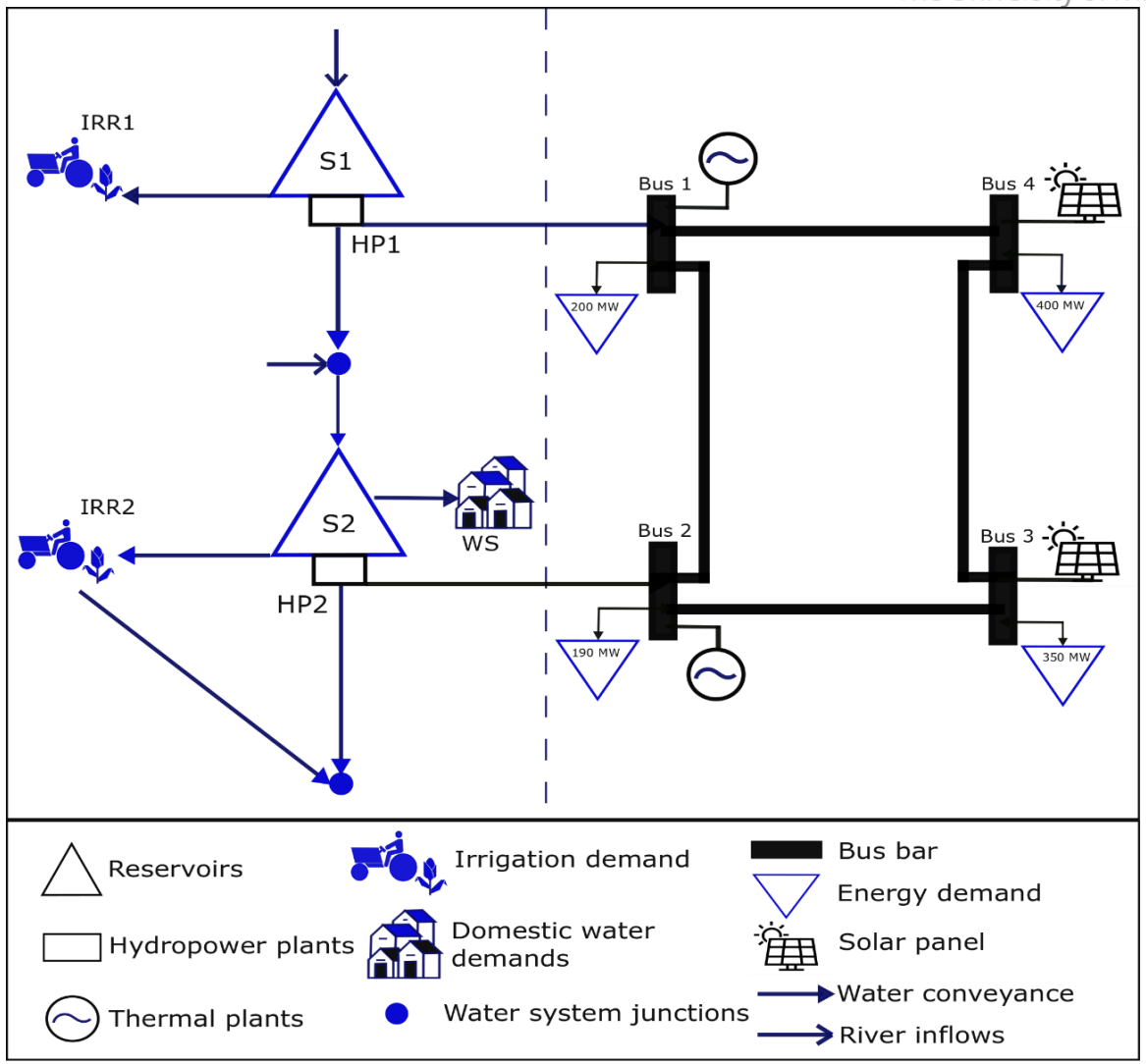


Image source: https://www.micro-hydro-power.com/hydro-turbine-generator/

$$Q_{S_i} = \frac{EDC\big(HP(t)\big)}{g\rho\eta h_{net}}$$

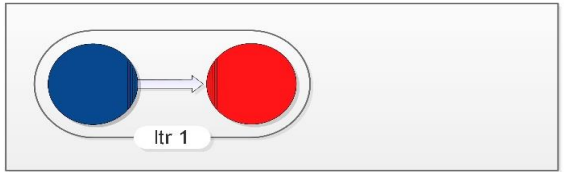
5- Case Study

- Modelled for 28 years at weekly time step
- Water and energy models linked through hydropower
- Cost of energy generation in decreasing order of conventional, hydropower and solar power generators

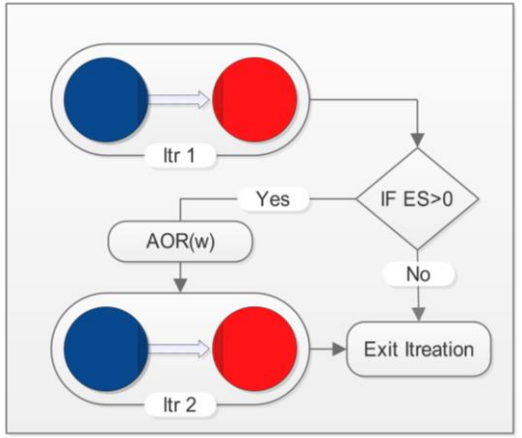


soft linked model setups

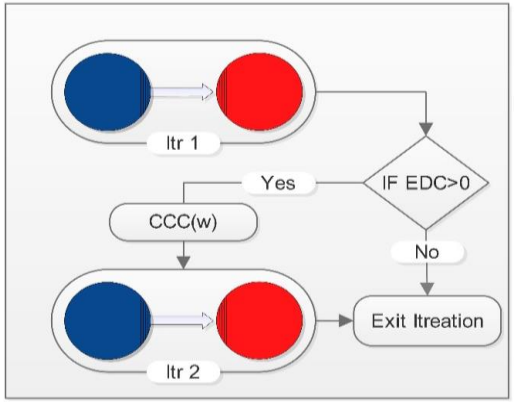
- A total of **six model setups** are implemented:
  - Four soft linked model setups (MS1 to MS4)
  - Two hard linked model setup (MS5 and MS6)
- Soft linked model uses optimized reservoir operating rule
  - An optimized reservoir operating rule was developed using multi-objective evolutionary algorithms (MOEA)
- Hard linked model uses reservoir scarcity cost curve



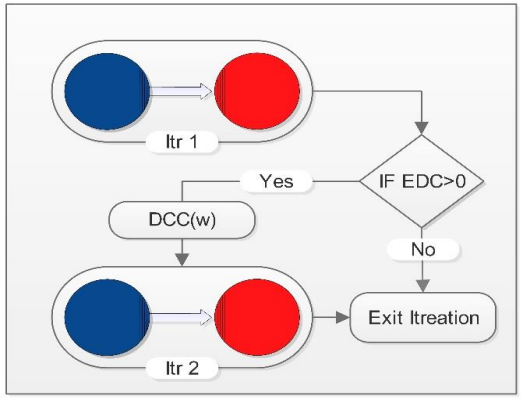
A) Model setup one (MS1) is a one-way communication where information transferred from water to energy model



B) Model setup two (MS2) is a two-way communication; energy model used to adjust reservoir operation release on the second iteration.



C) Model setup three (MS3) is a two-way communication; similar to model setup two but with different operational releases rule.



D) Model setup four (MS4) is a two-way communication; similar to model setup two but with different operational releases rule.

6- Result

Energy mix and generation pattern

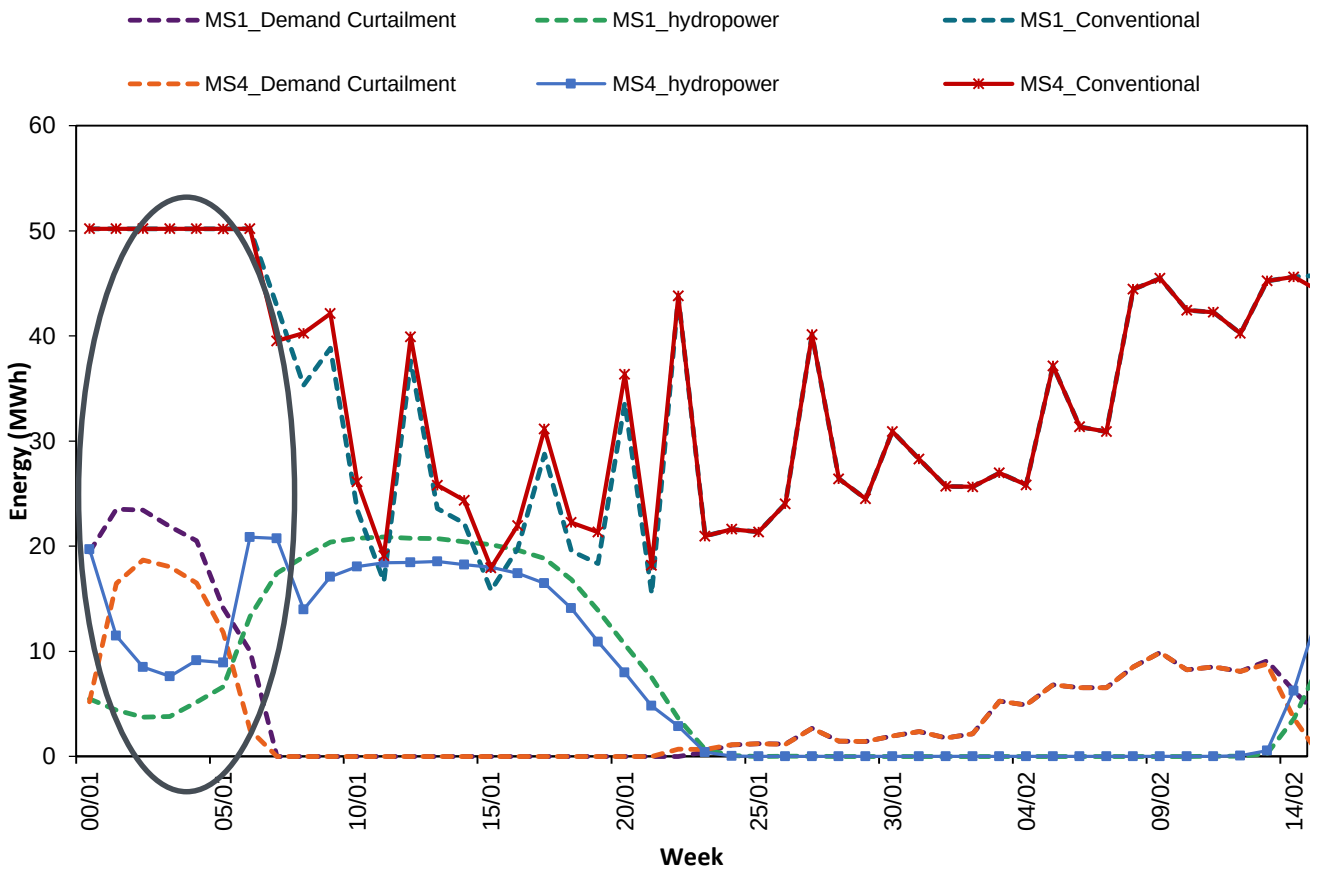
- There is a higher use of hydropower and conventional generation in hard-linked than soft-linked model setups
- In MS1, the sum of hydropower and renewable energy could exceeds the energy demand
- In MS1 hydropower generation could exceed the energy demand

Water-Energy Approach	Model Setups	Energy Curtailment (GWh)	Hydropower Generation (GWh)	Conventional Generation (GWh)	Renewable Energy (GWh)
Soft-Linked Model Setups	MS1	31.2	125	212	105
	MS2	30.7	127	210	105
	MS3	27	128	213	105
	MS4	24.6	127	216	105
Hard-Linked Model Setups	MS5	6.3	40	277	105
	MS6	0.5	146	220	105

6- Result

Energy mix and generation pattern

- An increase in the use of the hydropower and conventional generator in hard-linked than soft-linked model setups
- The sum of hydropower and renewable energy is in excess of the energy demand for MS1 compared to MS4



6- Result

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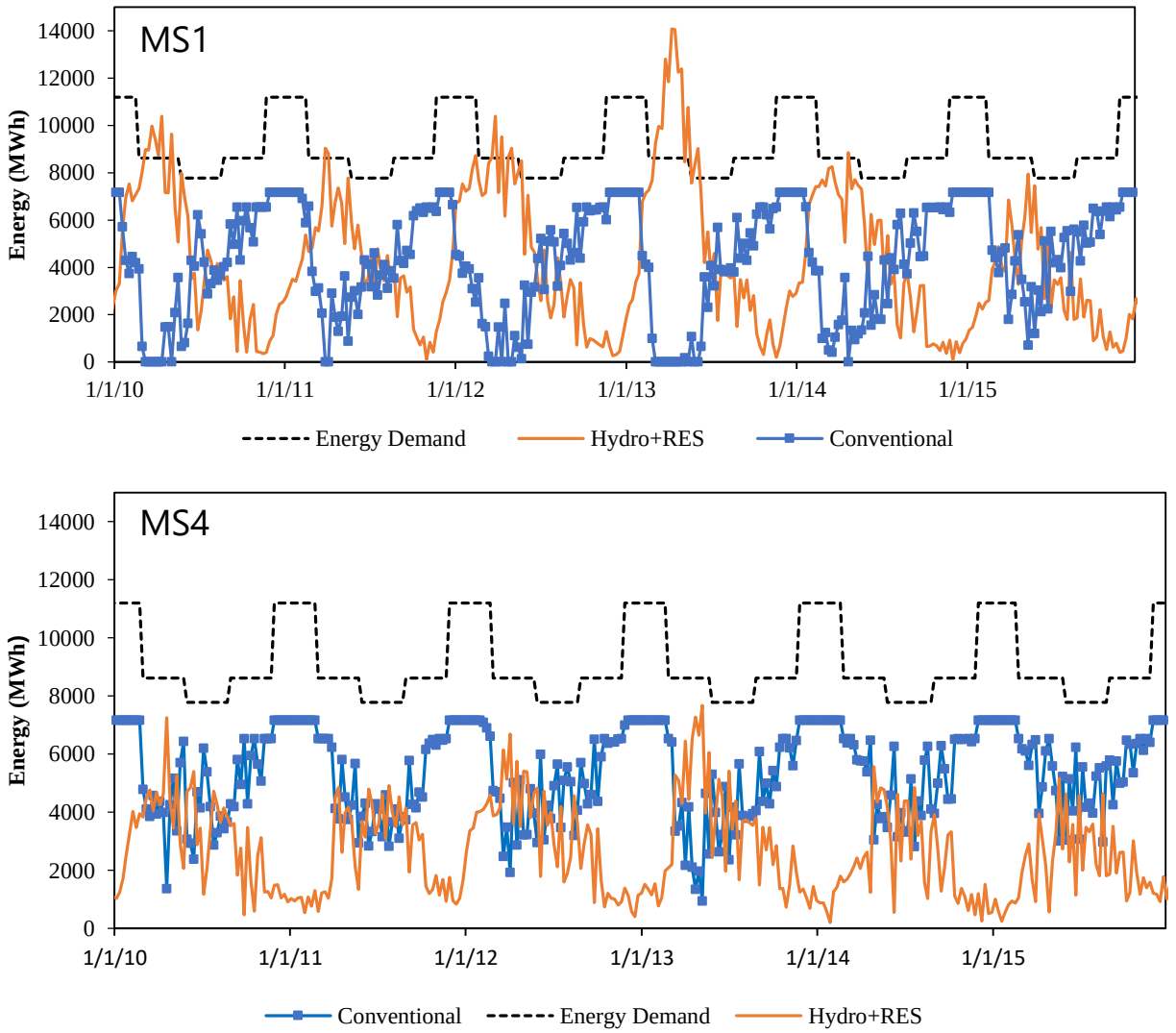
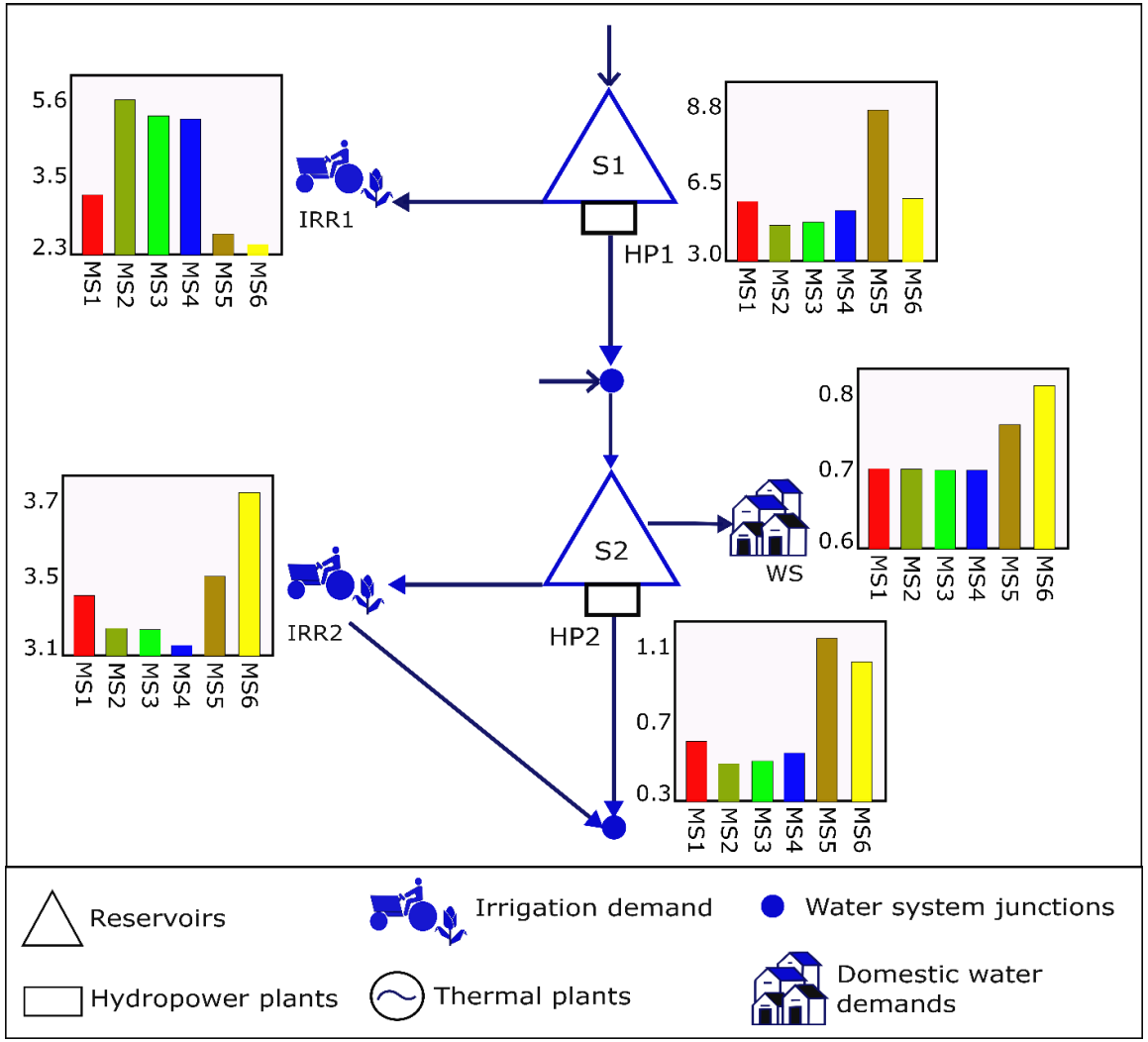


6- Result

Water allocation

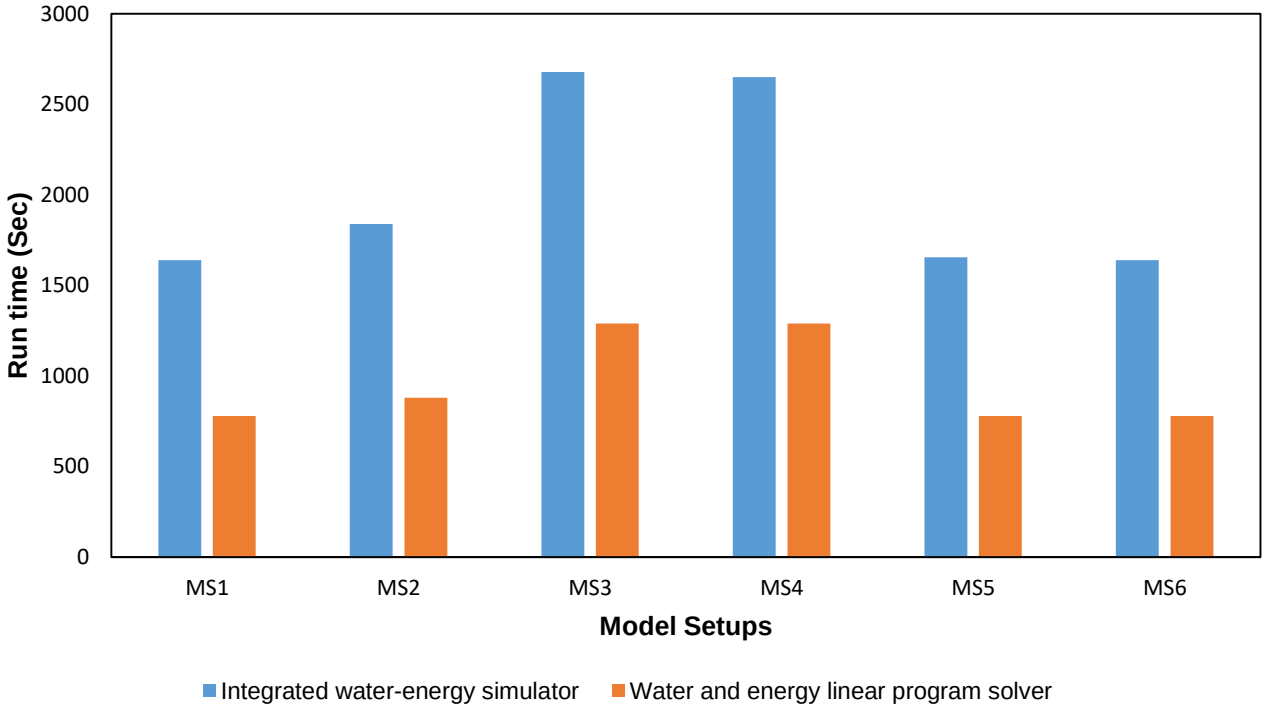
- Hard-linked models allocate more water for users with higher economic return across space while the soft-linked models follow the defined operating rule
- The hard-linked approach responds to energy demand curtailment by allocating more water
- Compared to the other soft-linked model setups, MS4 allocates higher water to hydropower generation



6- Result

Run time

- MS1 resulted in a lower computational time compared to all other model setups
- On average the time spent by the solver in the hard-linked formulation is lower than that in soft-linked formulation
- Models with two-way links can be resource intensive as a result of the iterations needed to pass data back and forth



7- Conclusion

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- Soft-linking approach
  - Suited for systems that use defined operating rules
  - Flexible to implement complex rule-based operation
  - One way communication is not suited for energy systems with considerable amounts of solar and wind energy sources
  - High transparency between the model and the modeller
- Hard-linked approach
  - A lower energy demand curtailment is noted
  - Cost-based water resource allocation
  - Computationally more efficient compared to the iterative soft-linking approach
    - Requires mixed integers programming to simulate discrete reservoir operation rule