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Coupled water-energy modelling to assess climate change impacts on the Iberian Power System system

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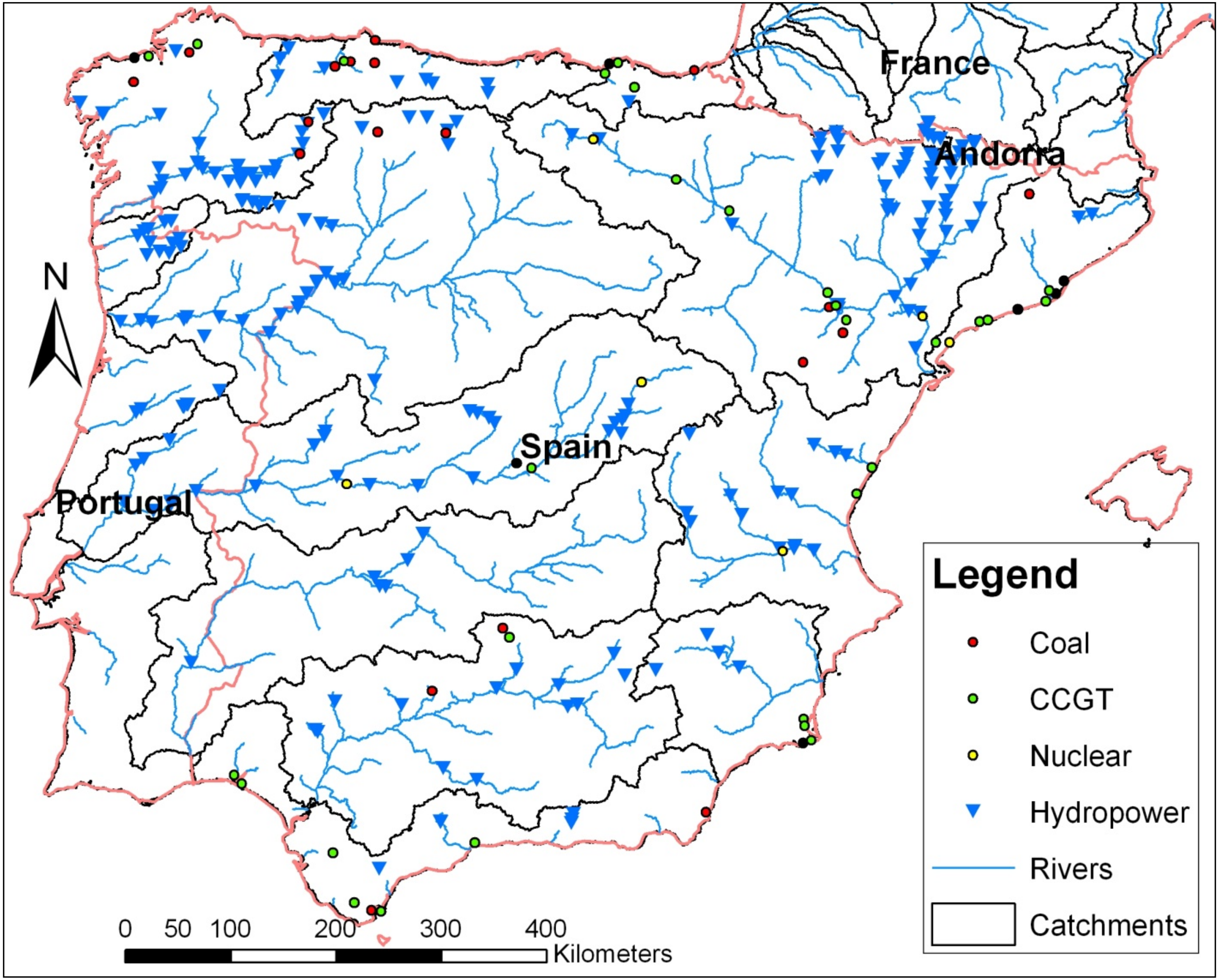
Silvio J. Pereira-Cardenal[1]*, Henrik Madsen[2], Niels D. Riegels[2], Roar Jensen[2], Karsten Arnbjerg-Nielsen[1], Peter Bauer-Gottwein[1]

1) Department of Environmental Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark
2) DHI Water and Environment, Hørsholm, Denmark

* Corresponding author: sjpc@env.dtu.dk


France
Andorra
Spain
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N
0
50
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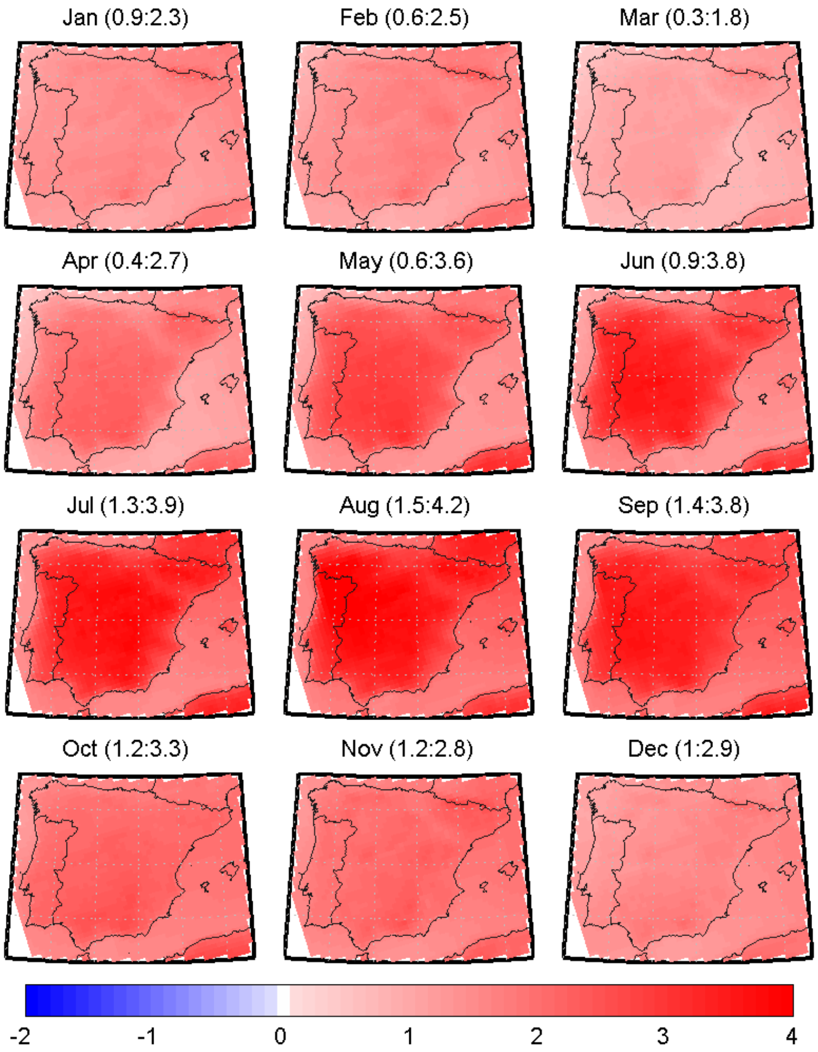
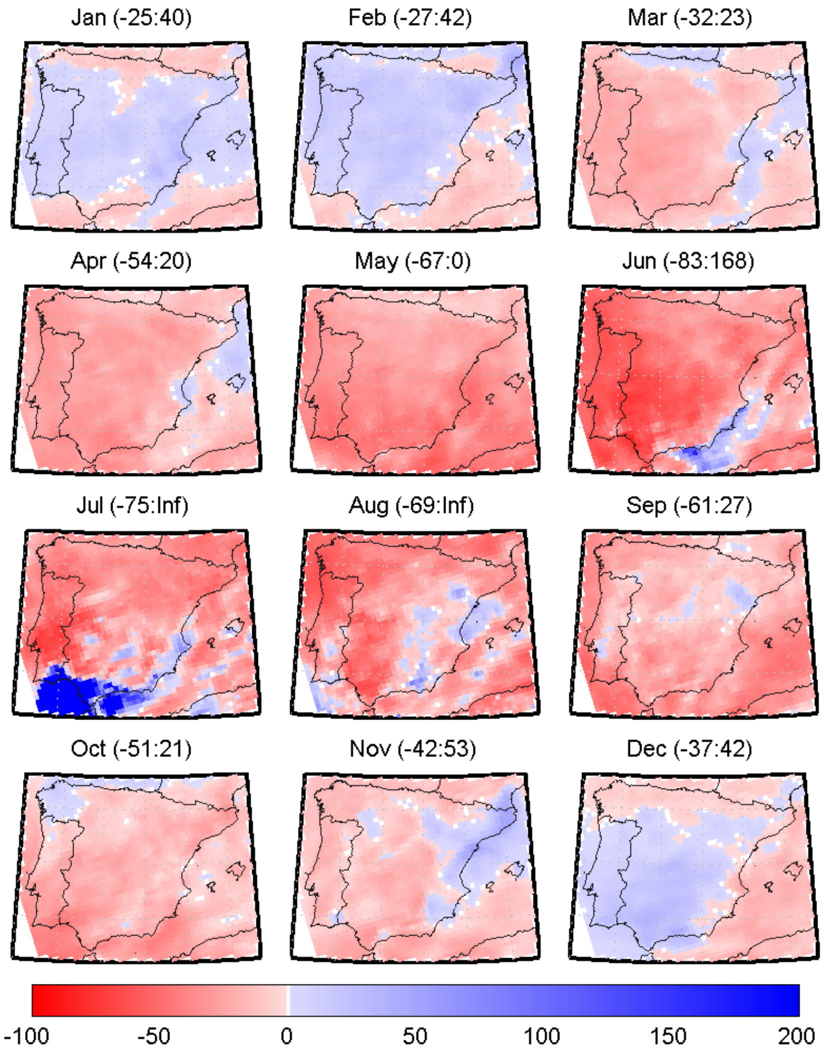
400
Kilometers
Legend
Coal
CCGT
Nuclear
Hydropower
Rivers
Catchments

Changes in temperature and precipitation (2036-2065)

Monthly Temperature Changes [°C]



Monthly Precipitation Changes [%]



Methods: Modelling the hydrological system

Rainfall-Runoff Model:

- NAM: DHI's lumped conceptual modelling system
- Daily simulation of discharge in the major catchments of Spain and Portugal (Ebro, Tajo, Duero, Guadalquivir, Guadiana, Jucar and Miño-Sil).

Input:

- Precipitation: Spain02 & PT02 gridded daily precipitation product 1950-2003
- Temperature: E-OBS gridded daily temperature 1950-2011
- Potential evapotranspiration: derived from daily temperature
- Calibration: daily discharge timeseries (Ministry of Environment ES; Water Inst. PT)

Climate change input timeseries:

- Delta change approach: calculate monthly precipitation and temperature change factors between current (1961-1990) and future (2036-2065) scenarios.
- Average of monthly change factors from 3 regional climage models:
  - CLM (HadCM)
  - RACMO (Echam5)
  - REMO (Echam5)

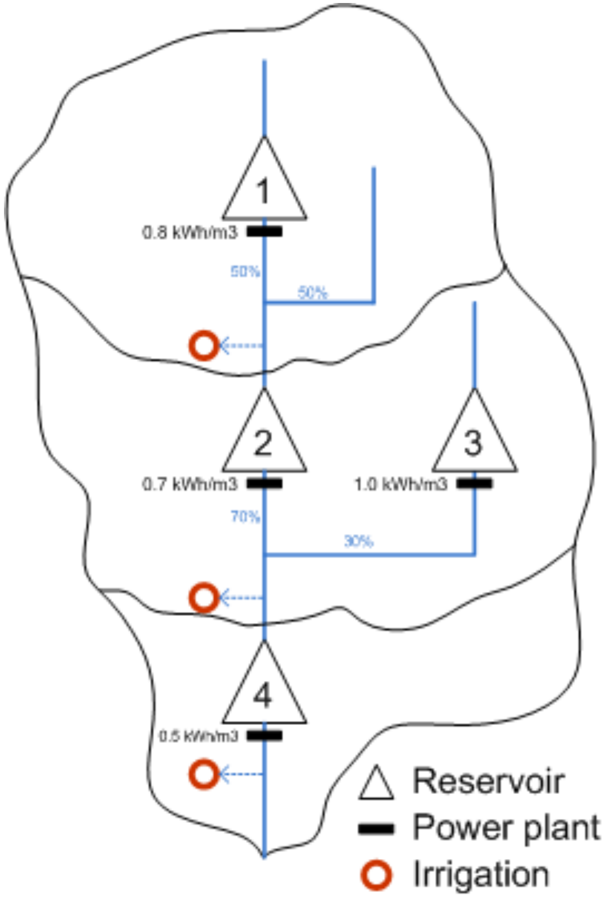
Oudin et al., 2005. Which PET input for a lumped RR model?
Sunyer et al., 2012. RCMs and statistical downscaling methods .

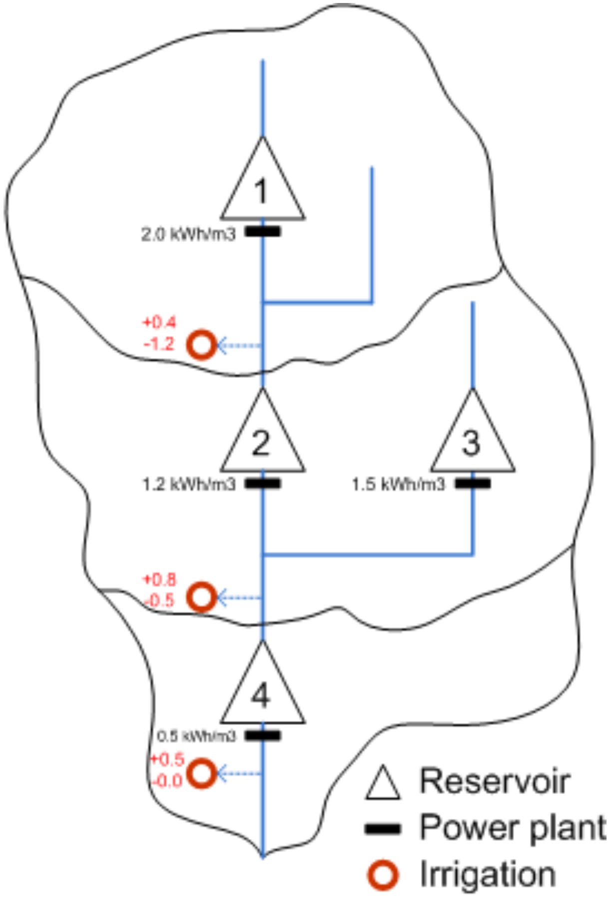
Methods: Reservoir aggregation

More than 1000 reservoirs in the Iberian Peninsula

All flows and volumes converted to power and energy (hydropower equation) and added.

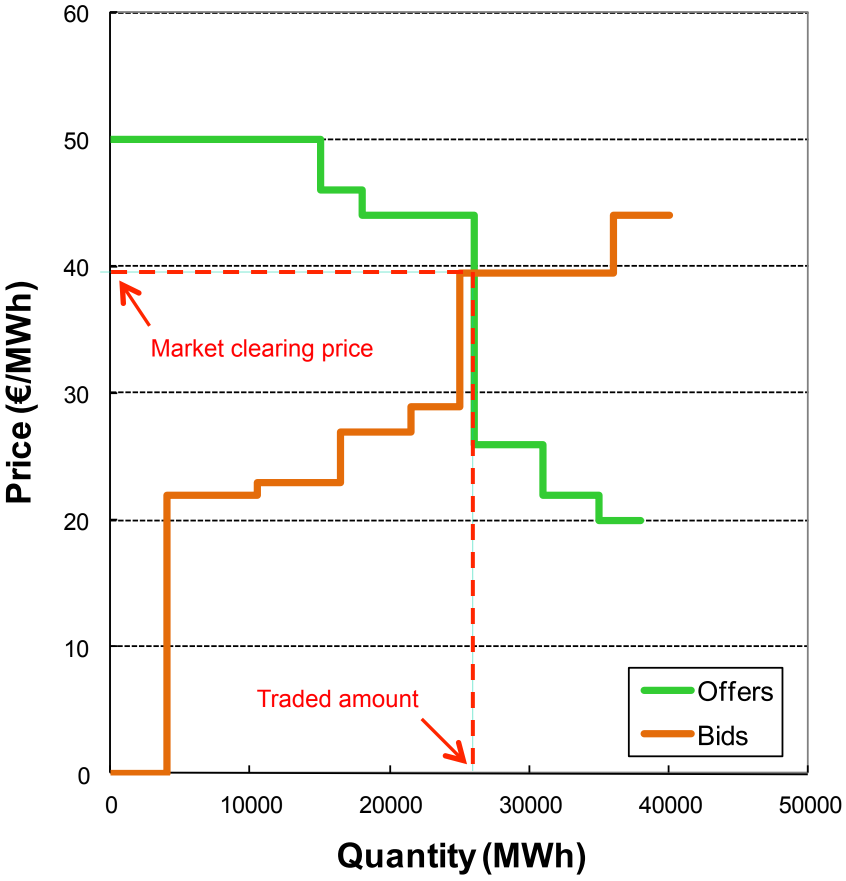
Irrigation schemes cause: 1. Minimum releases from upstream reservoirs
2. Flow abstractions from downstream reservoirs





Methods: Modelling the power system

	Company	Quantity MWh	Price €/MWh
Bids	Hydropower	4000	44.0
	Pumped storage	800	45.0
	Nuclear	4000	0.0
	CCGT	11000	39.5
	Thermal	5000	27.0
	Spec. Regime* A	6500	22.0
	Spec. Regime* B	3500	29.0
	Others	6000	23.0
Offers	Retailer 1	15000	50
	Retailer 2	3000	46
	Retailer 3	8000	44
	Large consumer 1	5000	26
	Large consumer 2	4000	22
	Large consumer 3	3000	20



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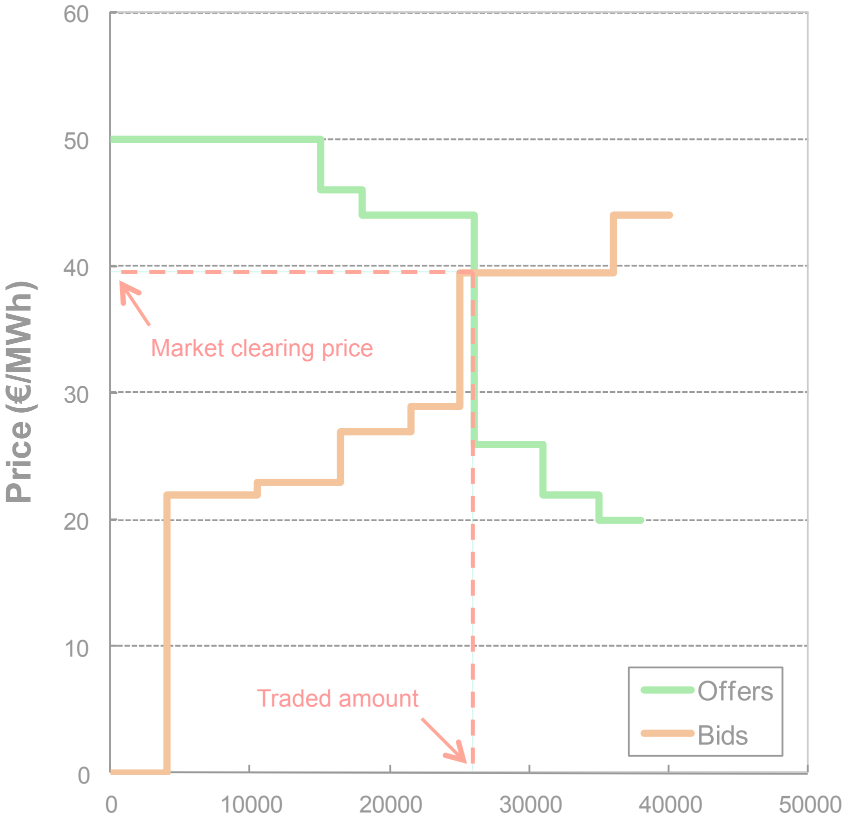


Power demand:

- inelastic, estimated through daily temperature series (cooling and heating degree days)

Power supply:

- Four technologies (nuclear, thermal, hydropower, renewables under special regime)
- Observed installed capacities (2008-2011)
- Marginal prices from CNE.

CNE, 2008. Propuesta de revisión de la tarifa eléctrica.

Valor et al., 2001. Daily air temperature and electricity load in Spain.

Methods: Joint optimization water-energy systems

Water value: the expected value of a marginal amount of water if it is stored for later use. Estimated through Stochastic Dynamic Programming (SDP) as follows:

Given a number of power and hydropower generation units $\boldsymbol{i}$, determine production levels $\boldsymbol{p_i}$ such as to minimize power production costs subject to meeting the power demand $\boldsymbol{d_t}$ and the irrigation demand $\boldsymbol{w_t}$ for every period $\boldsymbol{t}$ of the planning horizon $\boldsymbol{T}$.

SDP's recursive equation:

$$F_t^*\left(E_t, Q_{t-1}^k\right) = \min_{\mathbf{p}} \left[\mathbf{c}^T \mathbf{p} + \sum_{l=1}^{L} \left(a_{kl} \cdot F_{t+1}^*\left(E_{t+1}, Q_t^l\right)\right)\right]$$

Water balance:

$$E_t = E_{t-1} + Q_t - \mathbf{u}^T \mathbf{w}_t - H_t, \quad t = 1, \dots, S$$

Power balance:

$$\sum_{i=1}^{I} p_{i,t} = d_t - H_t, \quad t = 1, \dots, S$$

Min/max releases:

$$\underline{H} = \sum_{n=1}^{N} \mathbf{y}_n^T \underline{\mathbf{r}}_n \quad ; \quad \overline{H} = \sum_{n=1}^{N} \mathbf{y}_n^T \overline{\mathbf{r}}_n$$

Min/max storage:

$$\underline{E} = \sum_{n=1}^{N} \mathbf{z}_n^T \underline{\mathbf{v}}_n \quad ; \quad \overline{E} = \sum_{n=1}^{N} \mathbf{z}_n^T \overline{\mathbf{v}}_n$$

Irrigation demand:

$$\underline{H}_t = \mathbf{w}_t^T \mathbf{g}, \quad t = 1, \dots, S$$

F(E,Q): optimal value function

Et: *equivalent energy storage* [GWh]

Qt: *equivalent energy inflow* [GWh/week]

c: *constant marginal costs of non-hydro producers i* [€]

p: *production levels for producers i* [GWh/week]

a_{kl}: *transition probability from inflow* Q_t^k *to* Q_{t+1}^l

w: *downstream irrigation water demand* [m^3]

H: *hydropower production* [GWh/week]

Water to energy conversion factors:

y: *local energy equivalent* [kWh/m^3]

z: *total energy equivalent* [kWh/m^3]

u: *discharge energy content* [kWh/m^3]

g: *average energy production per discharge* [kWh/m^3]

Indeces:

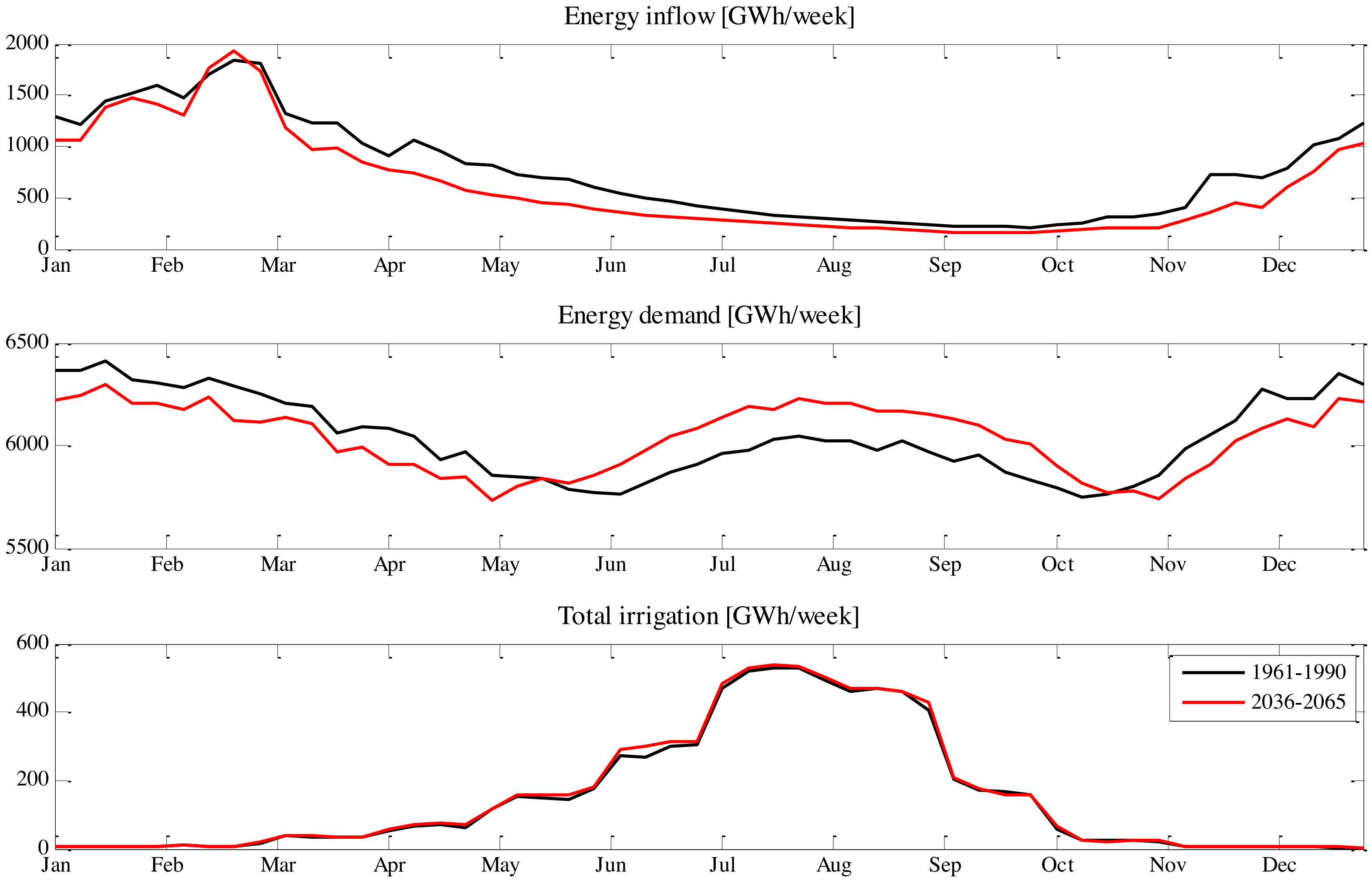
i: *non-hydro power producer index*

t: *time index*

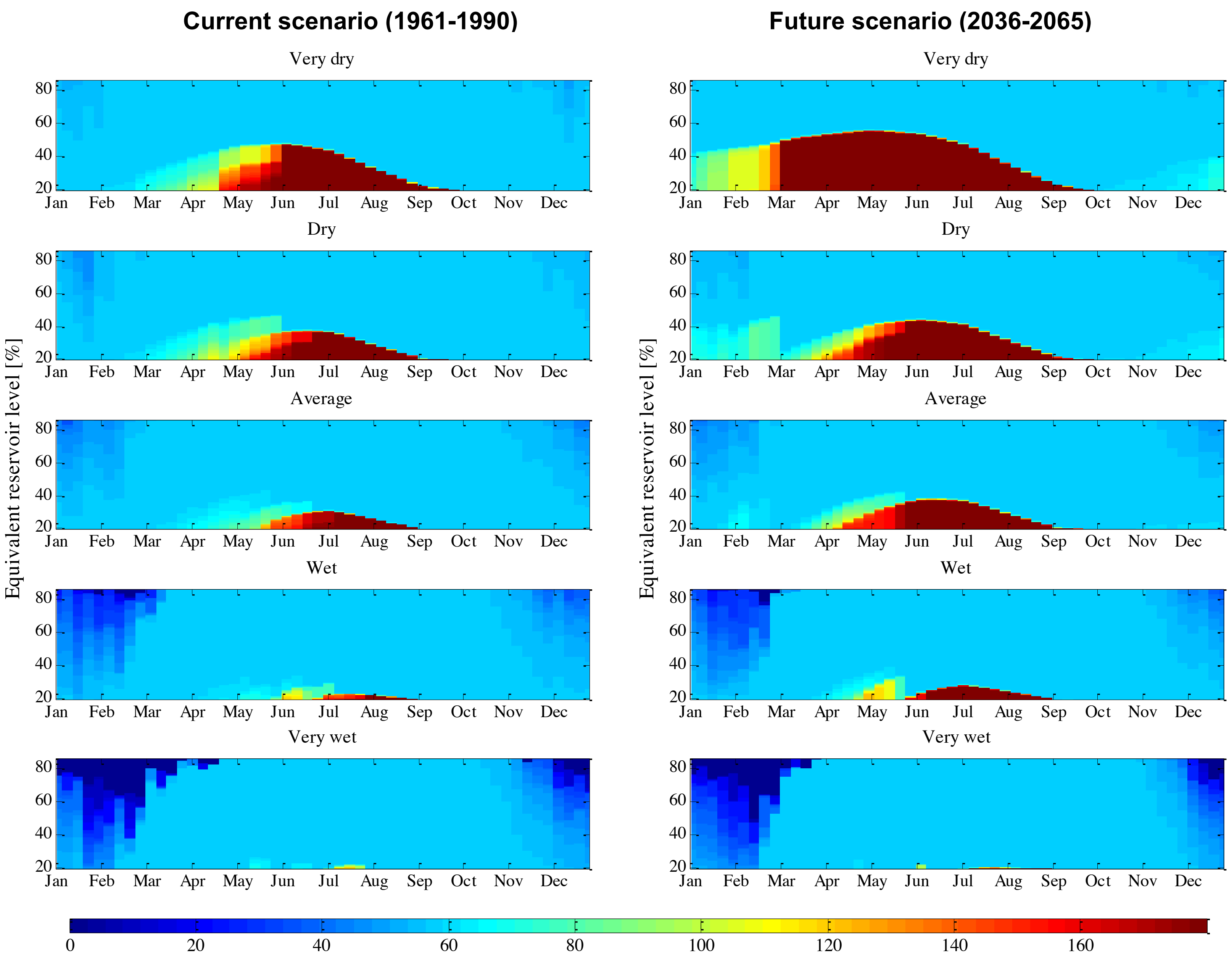
n: *catchment index*

k and l: *inflow scenario in week t and t+1, respectively*

Results: Variations in input timeseries



Results: Water value tables [€/MWh]



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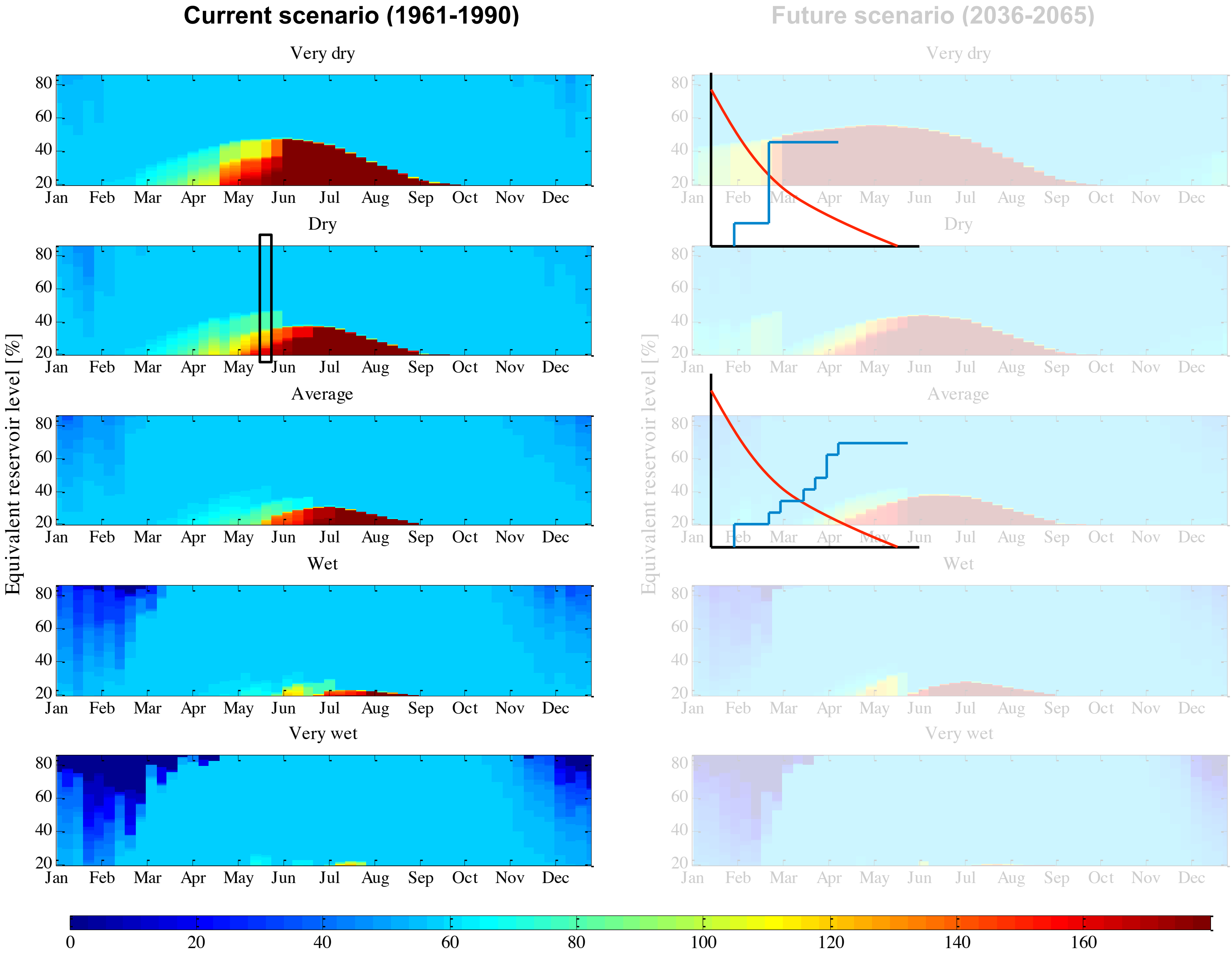
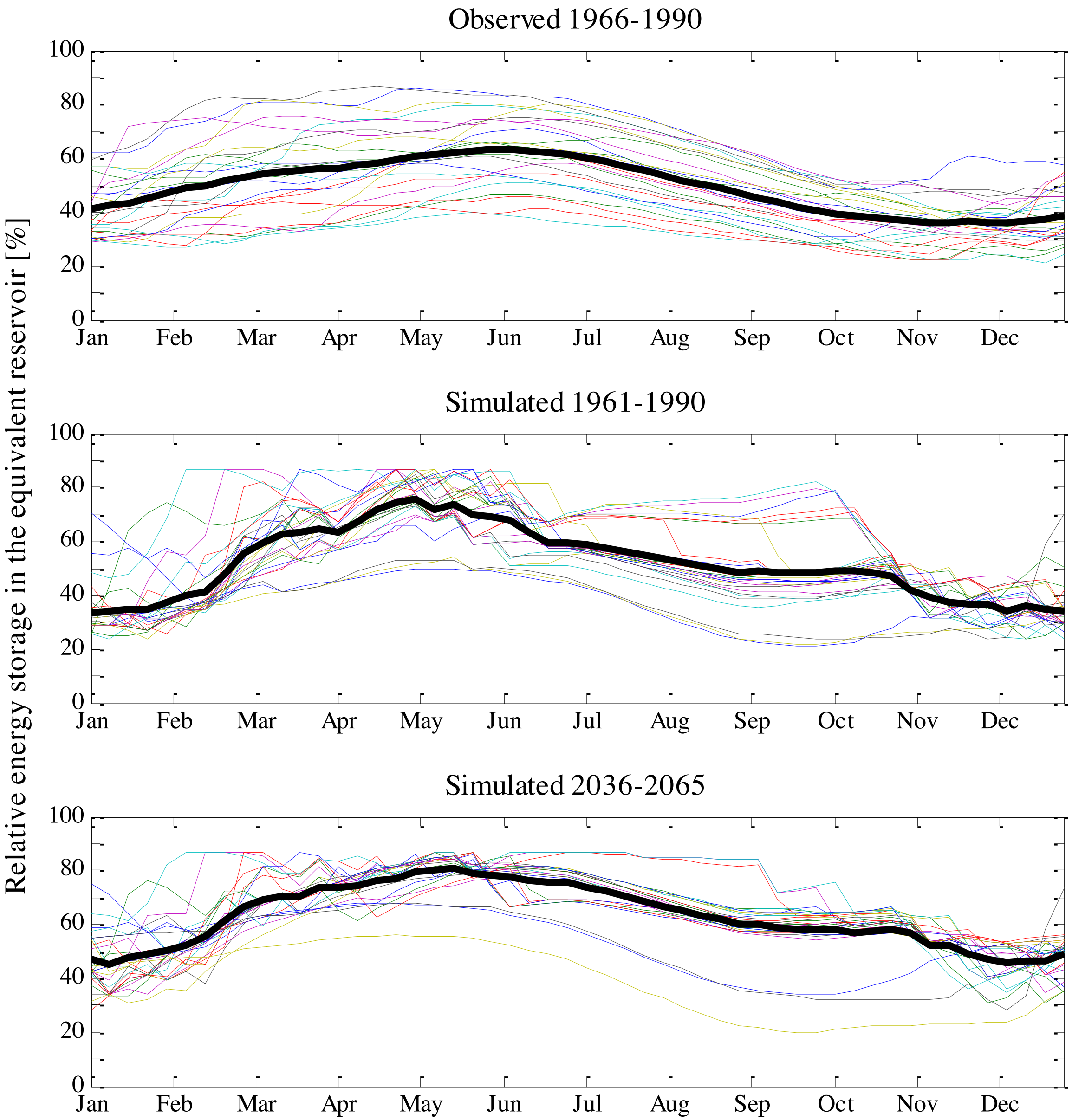


Results: Energy storage



Energy mix:

- Hydropower: 11.5%
- Nuclear: 17.8%
- Other thermal: 40.5%
- Special regime: 30.2%

CO2 emissions: 72.1 million tons/year

Energy mix:

- Hydropower: 8.9% **- 22%**
- Nuclear: 17.8%
- Other thermal: 43.1% **+ 8.7%**
- Special regime: 30.2%

CO2 emissions: 72.1 million tons/year **+ 6.2%**

Conclusions

- According to our results, runoff in the peninsula will decrease by 15%, reducing hydropower production by 22%.
- Summer inflow patterns will be more persistant (6 weeks v. 13 weeks)
- Power demand is likely to decrease in winter and to increase in summer, changing the trade-offs between hydropower and irrigation.
- If irrigation demands must be satisfied at all times, reservoirs will have to be managed more conservatively. This is caused by less water availability and more persistent dry/wet inflow patterns.
- Water values derived using SDP can support decision makers in reservoir management when facing:
  - Conflicting economic activities (e.g. hydropower and irrigation)
  - Uncertain future (water inflows, crop prices, etc.)

Acknowledgements

fiva
International Research School of Water Resources

DHI

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DE ESPAÑA

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DE MEDIO AMBIENTE
Y MEDIO RURAL Y MARINO

CONFEDERACIÓN
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