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Managing energy and water through modelling

Ignacio Hidalgo González

JRC Directorate C – Energy, Transport and Climate – Knowledge for the Energy Union Unit

Addressing the energy-water nexus through R&D planning and policies

IEA Experts' Group on R&D Priority Setting and Evaluation (EGRD)

Brussels, 28-29 May 2018

European Commission

Why does the JRC needs water-energy models?: the WEFE project

The interlinkages between the water and energy sectors may affect several EU policies:

- Water Framework Directive, Common Agriculture Policy, the Energy Union, EU Development Policy, Clean Energy for EU Islands…

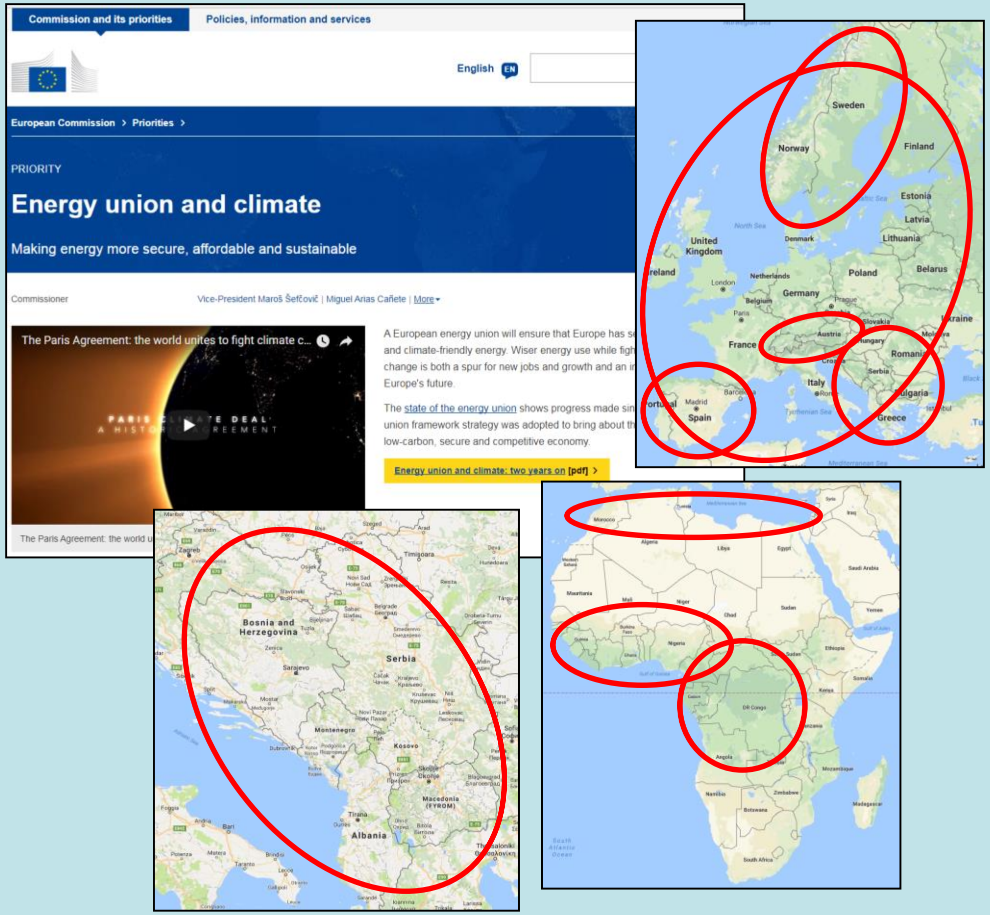
The JRC's Water-Energy-Food-Ecosystems (WEFE) nexus project provides scientific-based evidence for such policy considerations

A part of this project studies the water-energy nexus using model-based analyses

Goals of the water-energy modelling activities within WEFE-Energy

Goal: assess the current and future water-energy nexus to support impact assessments related to the Energy Union

- Understanding the impacts of water resources on the operation of the energy system, and vice versa
- Analysing and projecting water and energy requirements in different regions
- Producing insights for a better management of water and energy resources



Current work streams

Modelling of the water-energy nexus at continental scale

Modelling of the water-power nexus at regional (multi-country) scale

Modelling of the water-energy nexus at smaller scales (islands)

Current work streams

Modelling of the water-energy nexus at continental scale

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Modelling of the water-energy nexus at smaller scales (islands)

Modelling the water-energy nexus at continental scale: approach

Goal: to estimate projected fresh water consumption from the whole energy sector, combining:

Energy system-wide projections at country level

- Primary energy production: oil and gas extraction, coal and uranium mining
- Energy transformation: refineries and thermal power plants

Water withdrawal and consumption factors for different energy technologies

Additional energy sector data for

- Better estimating water consumptions from each energy sub-sector
- Downscaling to sub-national levels and sub-annual periods

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Modelling the water-energy nexus at continental scale: data sources and needs

Energy system-wide projections at country level

- Europe: EU Energy Reference Scenario
- Africa: Africa Energy Outlook 2040, WEO, AEO, BP Outlook, JRC GECO, KTH projections

Water withdrawal and consumption factors for different energy production and transformation processes

- JRC literature review and own estimations

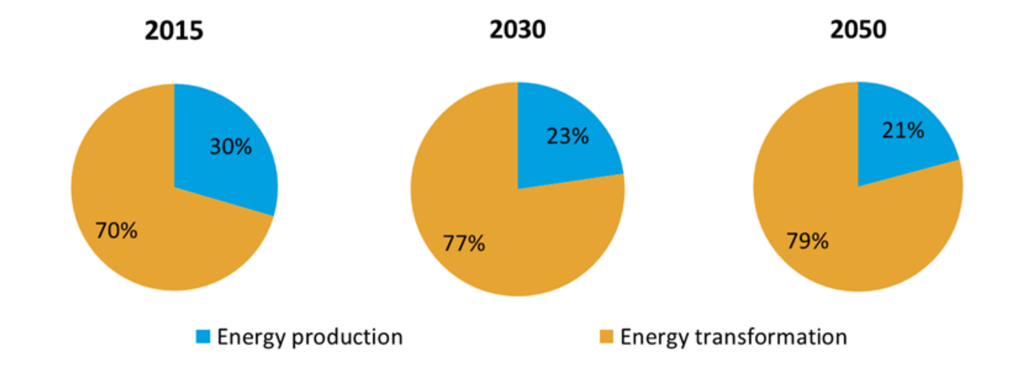
Additional energy sector data

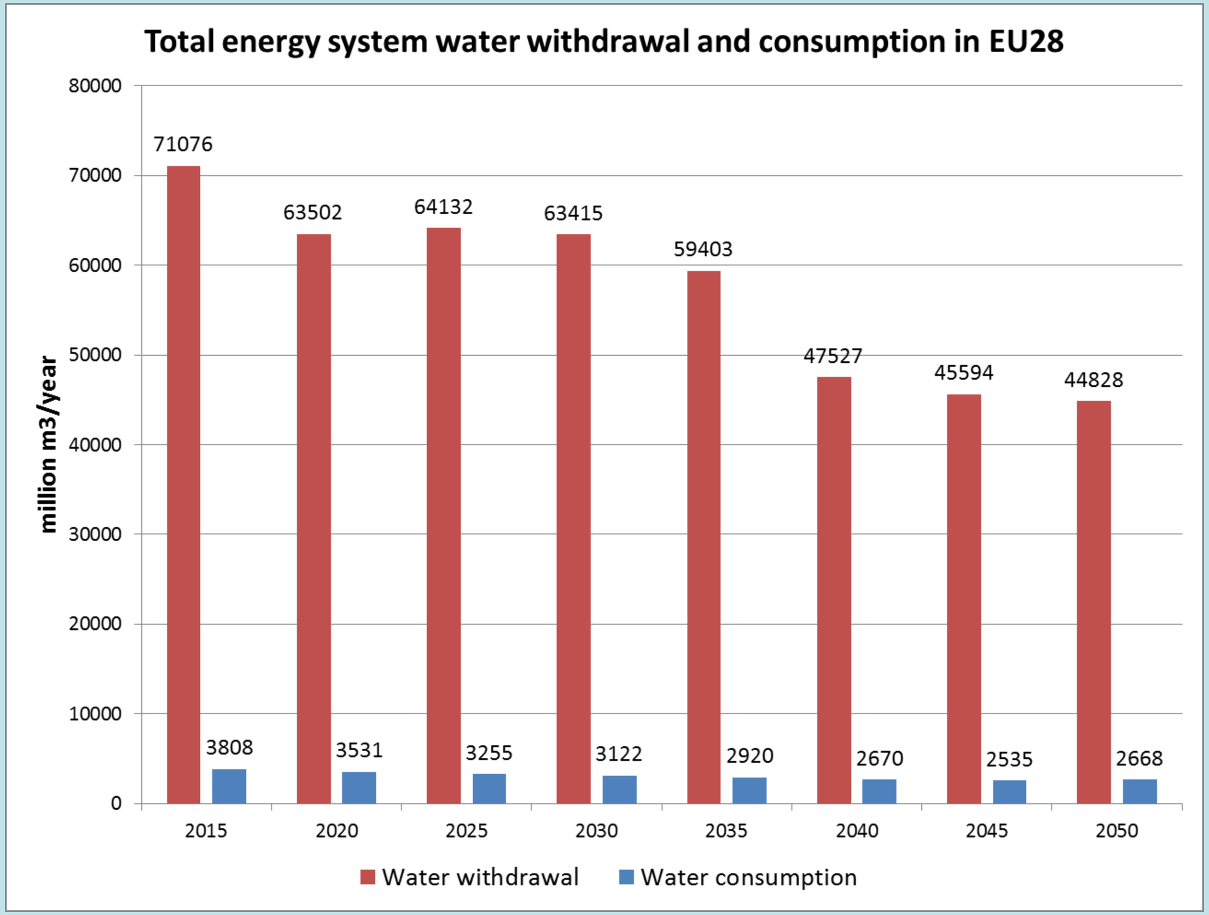
- JRC own data on power plants
- Commercial: oil and gas fields (Rystad Energy), mining projects (S&P Global), refineries (Oil and Gas Journal)
- Public: ENTSO-E, WRI, Energydata.info, USGS

Modelling the water-energy nexus at continental scale: examples of results

Projected (2000-2050) fresh water demand at country level from

- Primary energy production: oil and gas extraction, coal and uranium mining
- Energy transformation: refineries and thermal power plants





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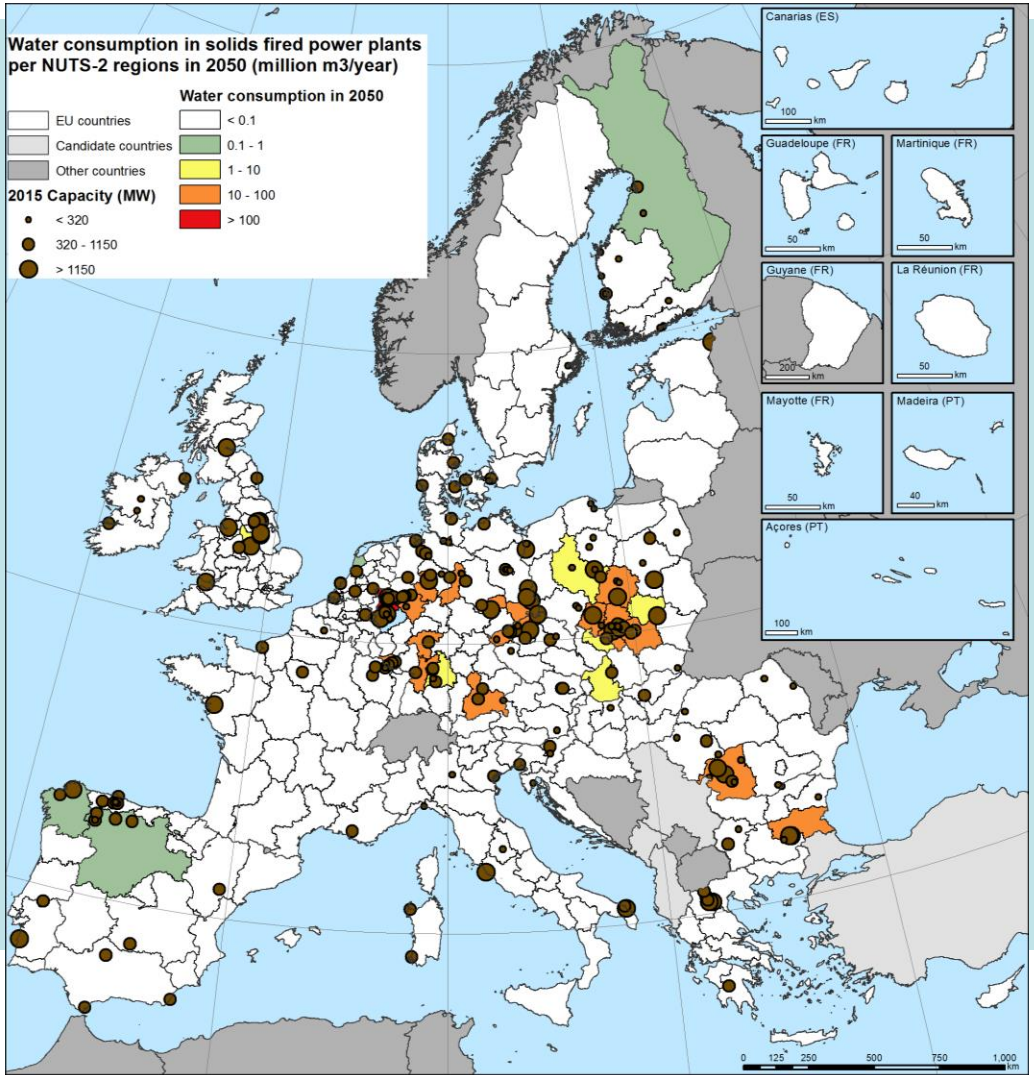
Modelling the water-energy nexus at continental scale: examples of results



Additional results for Europe

- Downscaled water demands to NUTS-2 (or to facility level)
- Downscaled water demands to monthly level (ongoing work)

Current work streams

Modelling of the water-energy nexus at continental scale

Modelling of the water-power nexus at regional (multi-country) scale

Modelling of the water-energy nexus at smaller scales (islands)

Modelling the water-power nexus at regional scale: Dispa-SET and LISFLOOD

Goal: integrated water and power system modelling to understand the impacts of water resources on the operation of the power system, and vice versa

LISFLOOD: hydrological rainfall-runoff model that simulates the hydrological processes at catchment level

Dispa-SET: open source (EUPL) model of large-scale power systems

- **Dispa-SET MTHC**: mid-term hydrothermal coordination module
- **Dispa-SET UCD**: unit commitment and dispatch module

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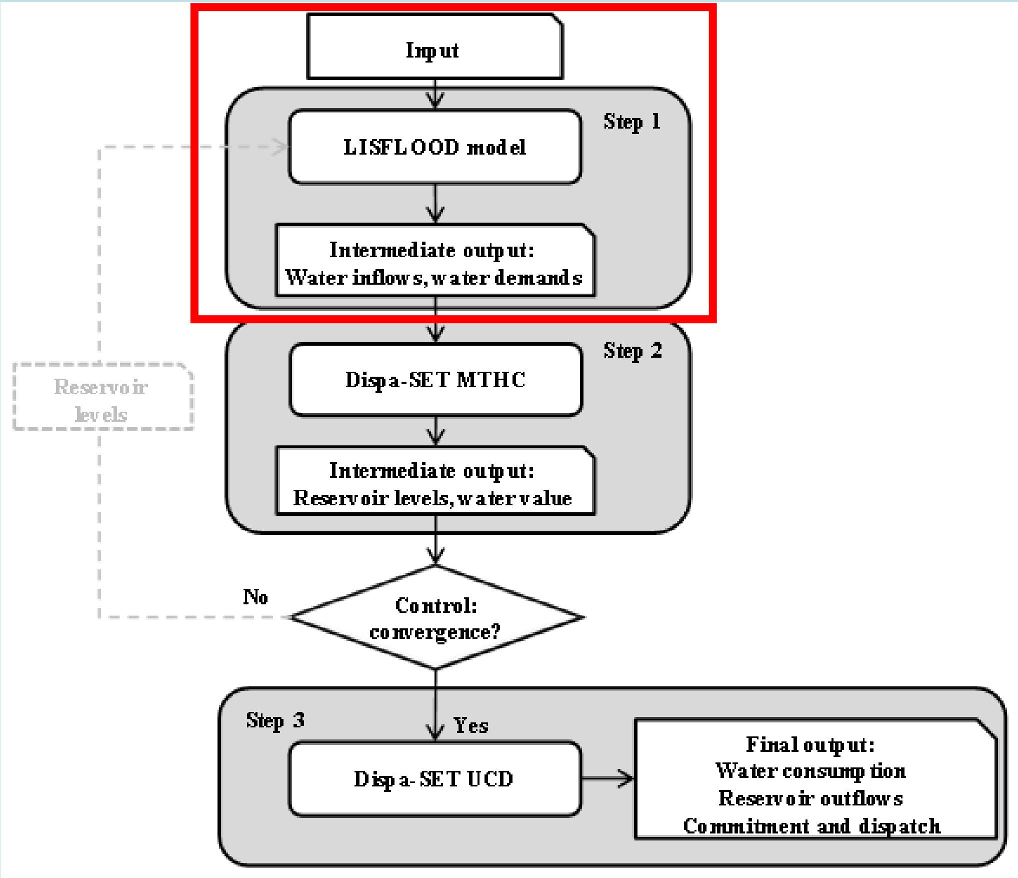
Modelling the water-power nexus at regional scale: approach

Step 1:

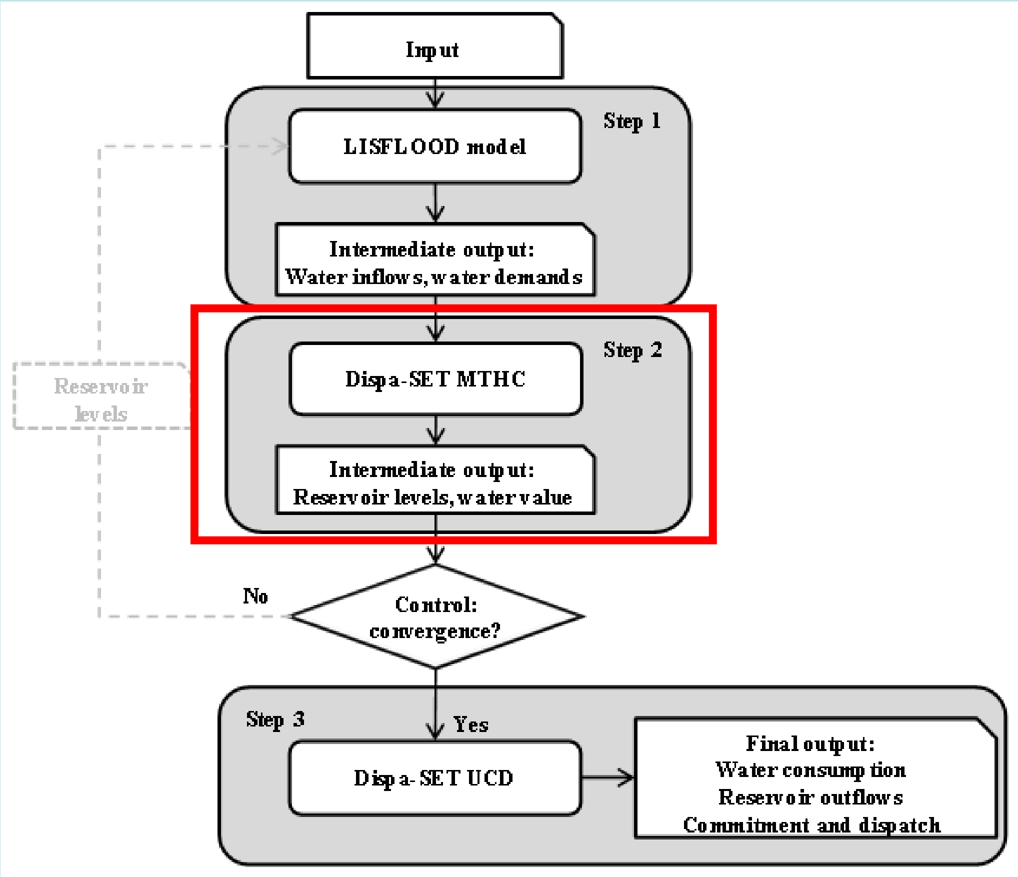
LISFLOOD provides water inflows and water demands into the Dispa-SET model, which constraint the operation of hydropower (storage levels and output) and thermal power plants (cooling).



Modelling the water-power nexus at regional scale: Dispa-SET and LISFLOOD

Step 2:

Dispa-SET MTHC runs in deterministic or stochastic mode at daily, weekly or monthly time steps during one or several years in order to provide the management of water resources (reservoir levels of hydropower plants) in the mid-term.

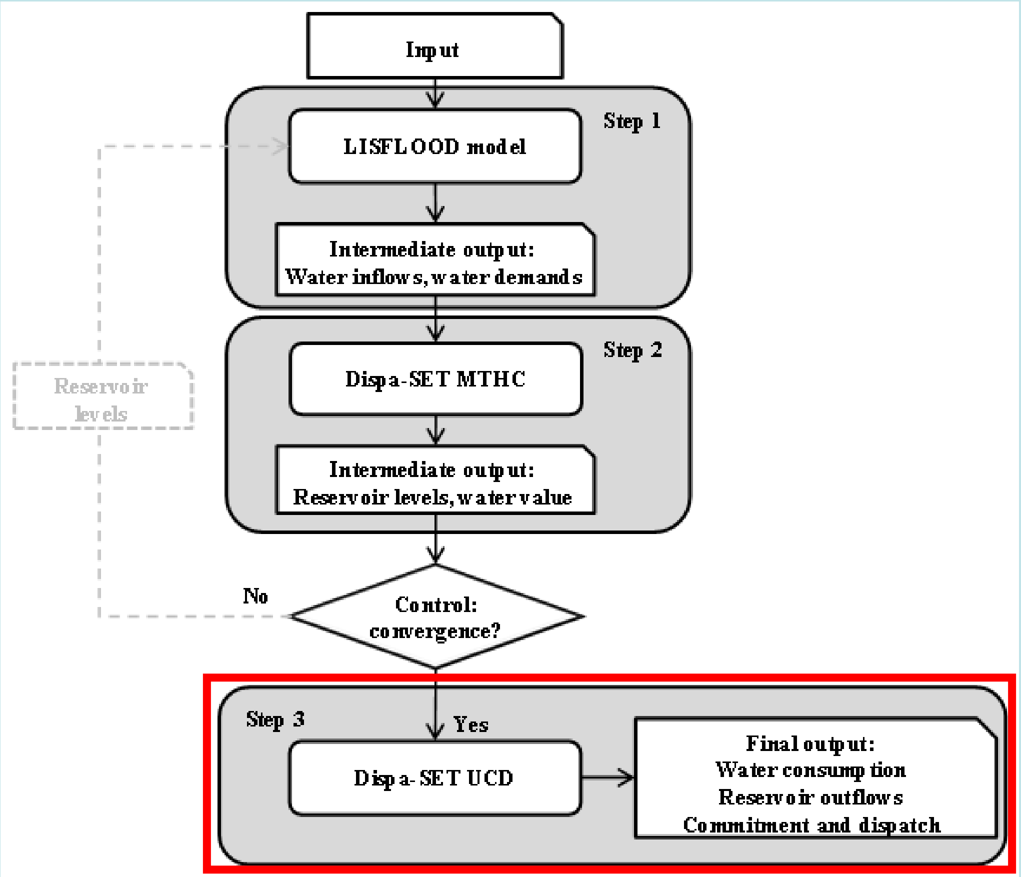


Modelling the water-power nexus at regional scale: Dispa-SET and LISFLOOD

Step 3:

Dispa-SET UCD runs at hourly time steps during a target year producing:

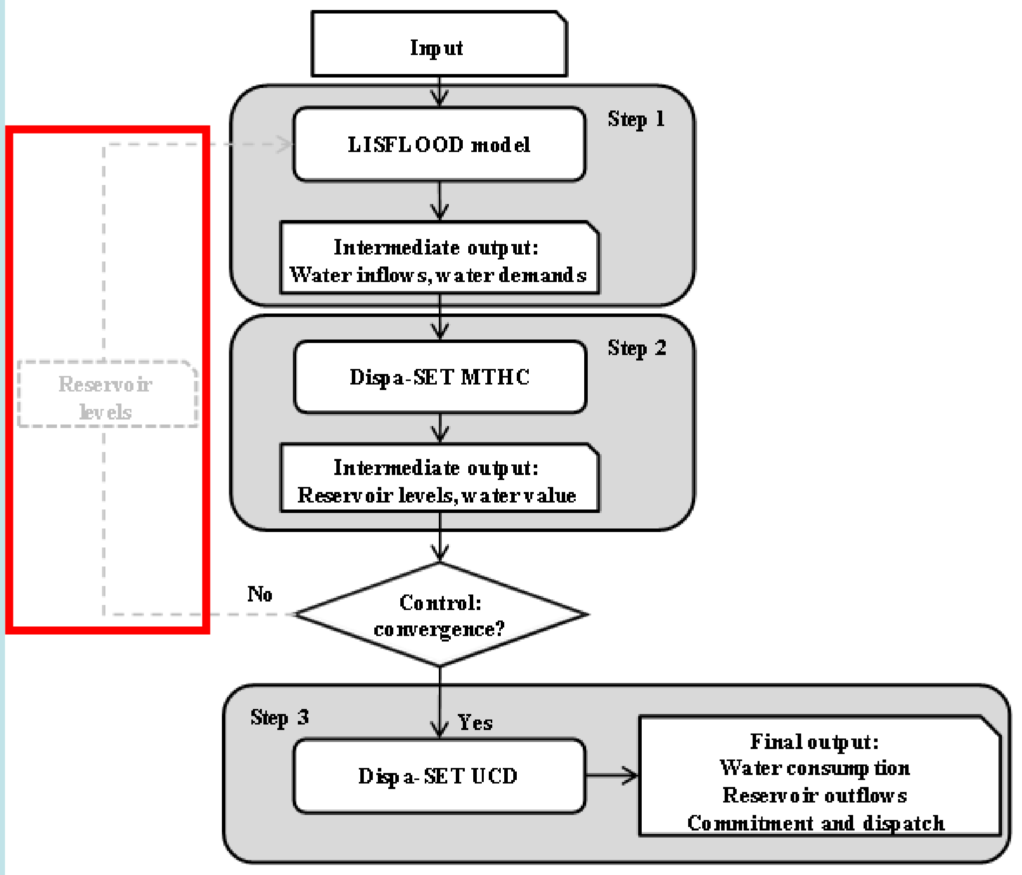
1) the power schedule and dispatch per unit,
2) water-related outcomes (e.g., water withdrawn and consumed by power plants, water stress indexes),
3) economic results (proxies of power prices, generation costs, water values),
4) emissions from thermal plants.



Modelling the water-power nexus at regional scale: Dispa-SET and LISFLOOD

Step 4 (ongoing work):

Ideally Dispa-SET and LISFLOOD should be run iteratively until reaching a stable solution. The stopping criteria may be based on the reservoir levels so that a set of adequate and optimised levels is derived.



Modelling the water-power nexus at regional scale: data needs and sources

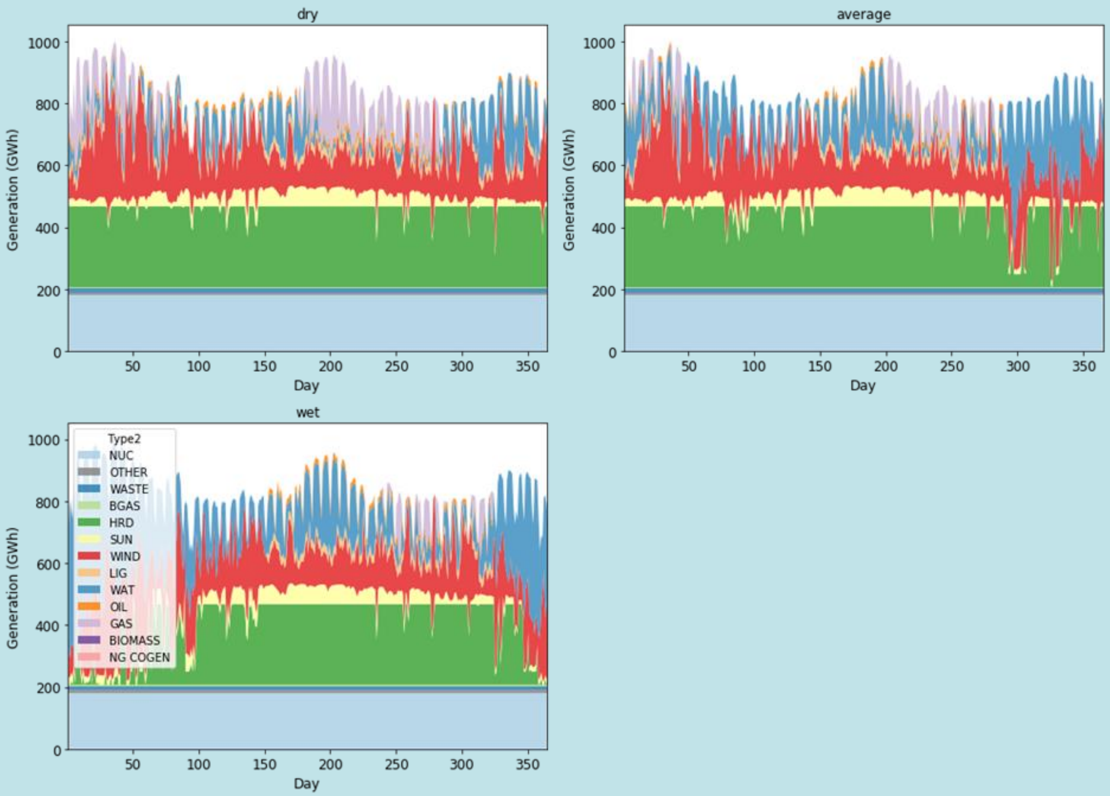
Highly complex and data intensive
Only part of the data available

Thermal power plant data
Plant name, location (longitude and latitude)
Technology type and fuel
Installed capacity
Efficiencies at different loads
Minimum load
Ramp rates, start-up times, minimum up and down times
Start-up costs
CHP (power to heat ratio, maximum heat production, heat storage…)
Water withdrawal and consumption factors
Cooling system
Water source (location and type)

Hydropower plant data
Plant name and location (longitude and latitude of the dam)
Technology type (reservoir, pumped storage, or run of river)
Installed capacity
Dam height
Head
Volume-head relation
Pumping efficiency
Reservoir capacity (volume or energy)
Minimum and maximum storage levels
Minimum and maximum outflow
Network data (connected dams)

Time series
Power load per zone
Historical power generation per zone and unit
Outages per unit
Fuel prices
Availability factors of renewable power plants (wind, solar, run of river)
Hydropower units (inflows, outflows, spillages, minimum and maximum flows, reservoir levels)
Interconnection capacities between zones

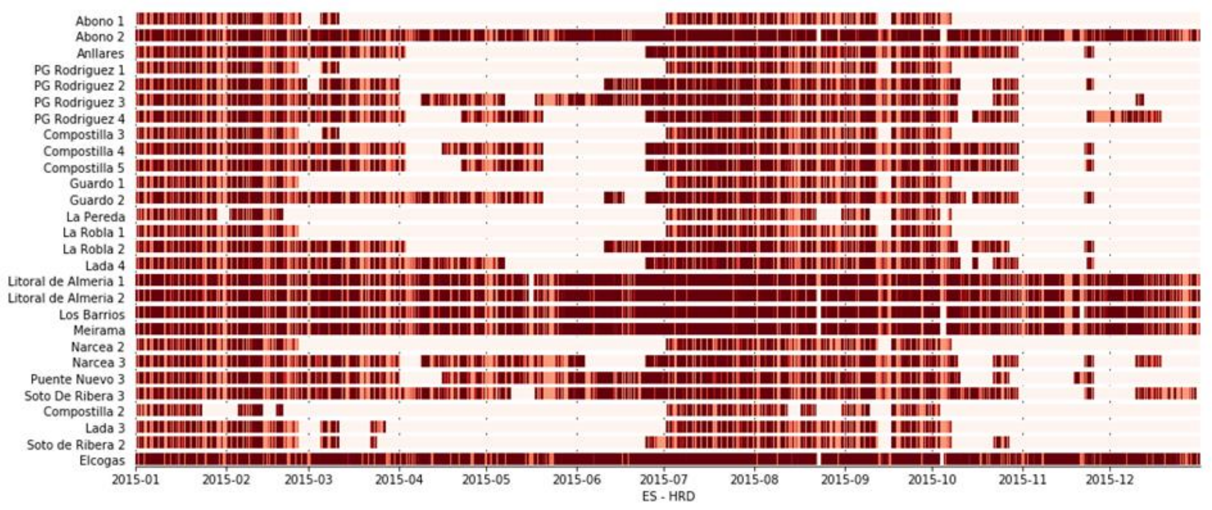
Modelling the water-power nexus at regional scale: examples of results



Daily power generation per scenario and fuel type

Operational results

Power schedule and dispatch, storage levels, load shedding, curtailment, flows through interconnections

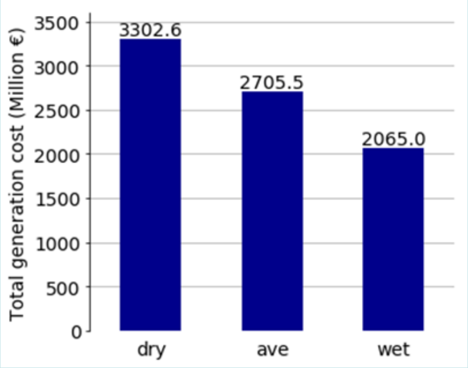


Hourly power dispatch and unit commitment of hard coal units

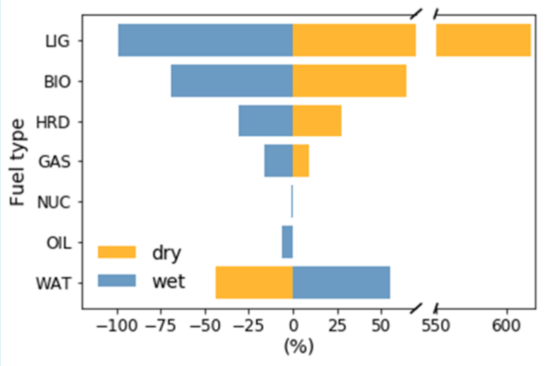
Modelling the water-power nexus at regional scale: examples of results

Economic results

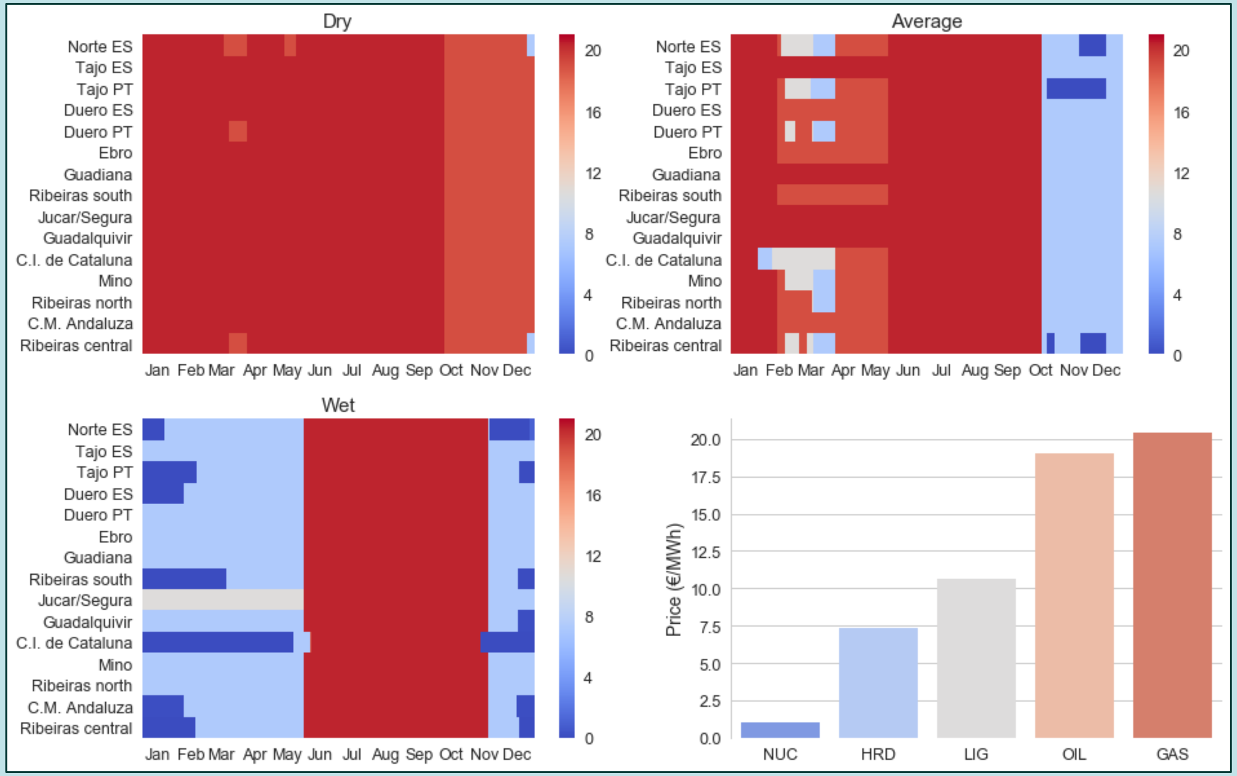
Average electricity cost, water values, system costs



System costs per scenario



Changes in production per scenario



Water values per catchment, period and scenario; fuel prices (bottom right)

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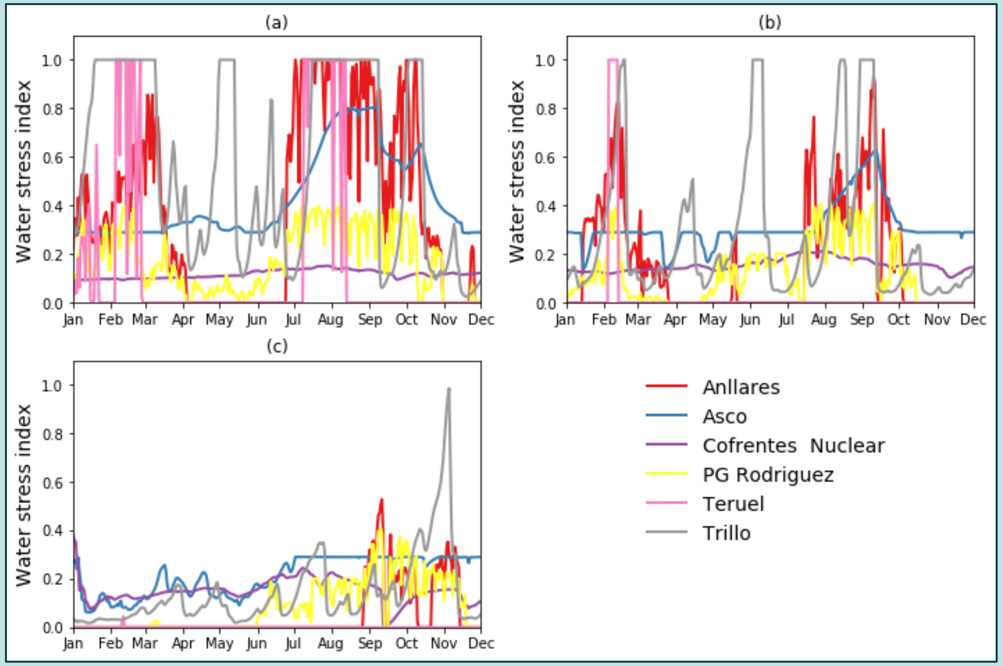
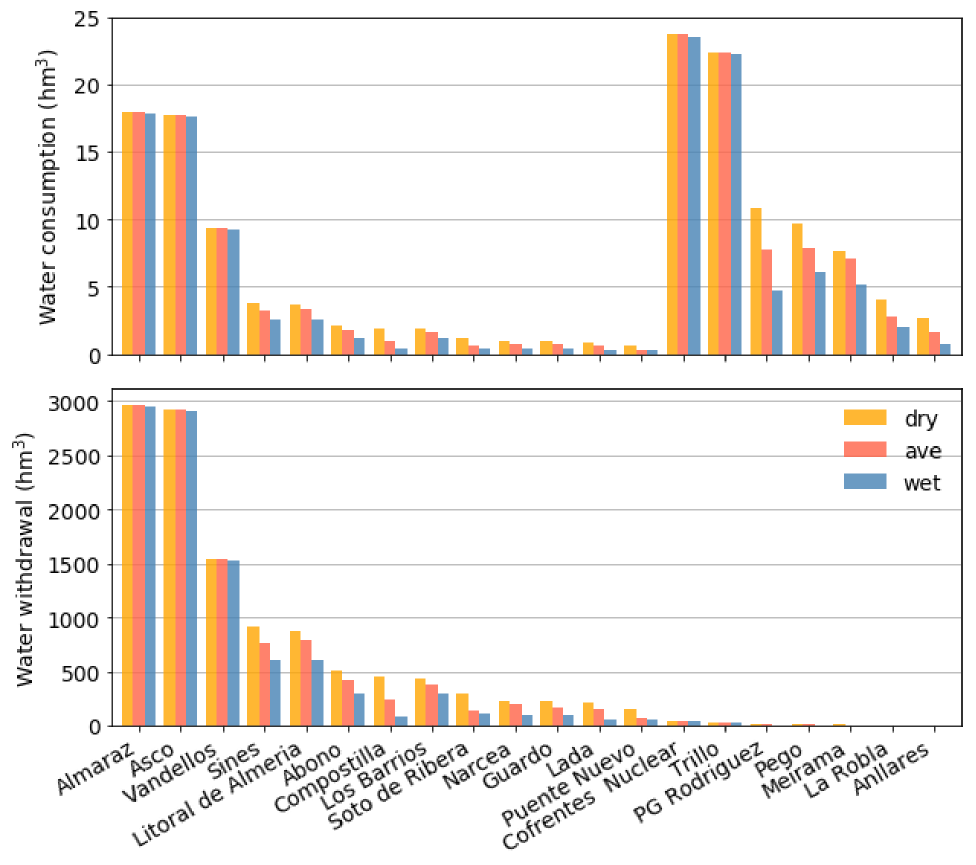
Modelling the water-power nexus at regional scale: examples of results

Environmental results

Water withdrawn and consumed, water stress indexes, spillages, emissions from thermal plants



Water stress of selected power plants in dry (a), average (b) and wet (c) scenarios

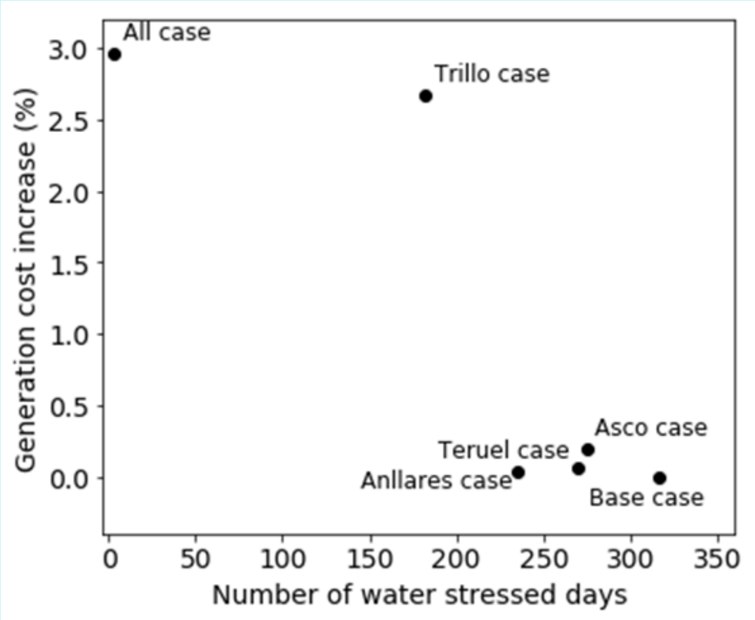


Water withdrawal and consumption of selected power plants

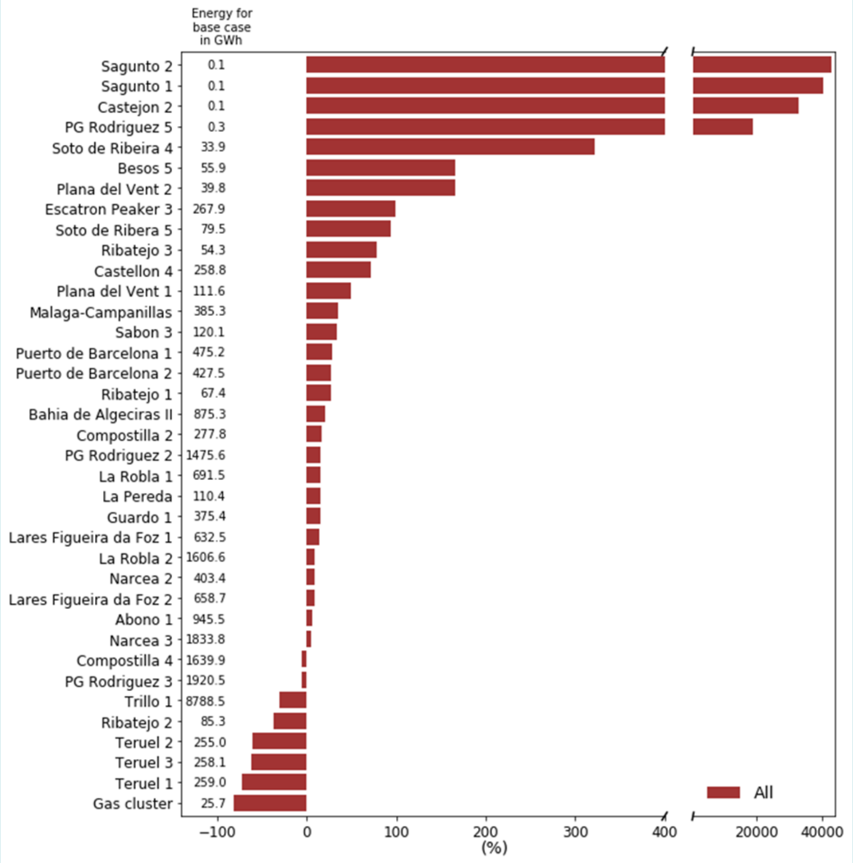
Modelling the water-power nexus at regional scale: examples of results

Simulated policies

Limits on withdrawals, water temperatures, allowed stress indexes



System cost increase versus number of water stressed days

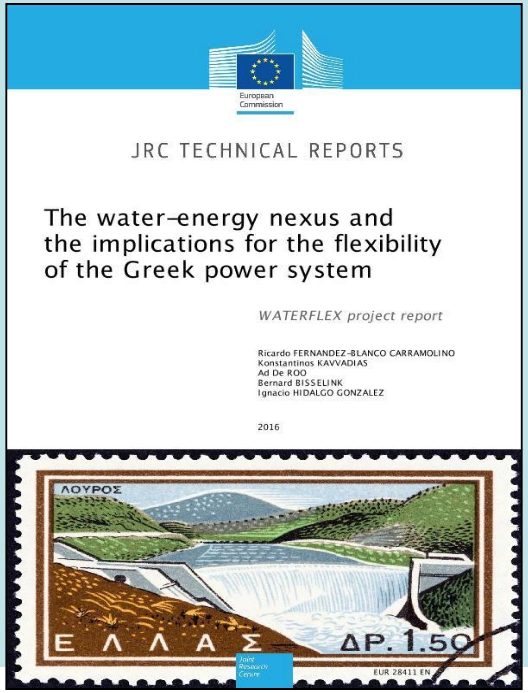


Variation of annual energy production per power plant

Modelling the water-power nexus at regional scale: examples of results

Available examples

- Case studies for Greece and the Iberian Peninsula
- Ongoing work on African power pools (WAPP and SAPP)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JRC TECHNICAL REPORTS

The water–energy nexus and the implications for the flexibility of the Greek power system

WATERFLEX project report

Ricardo FERNANDEZ-BLANCO CARRAMOLINO
Konstantinos KAVVADIAS
Ad De ROO
Bernard BISSELINK
Ignacio HIDALGO GONZALEZ

2016

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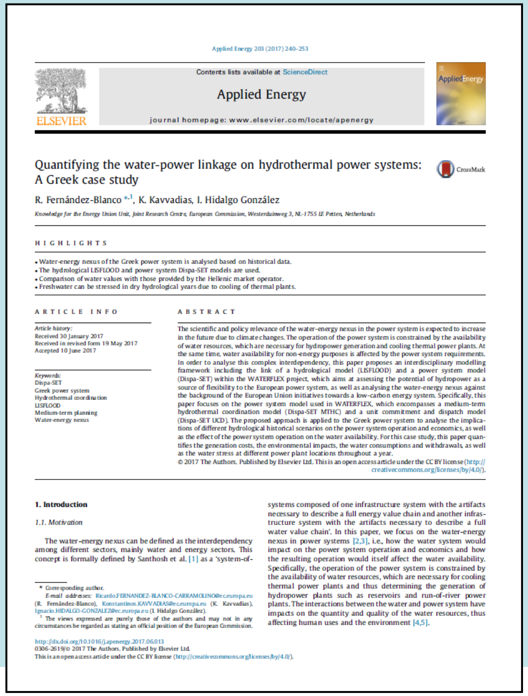
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Quantifying the water-power linkage on hydrothermal power systems: A Greek case study

R. Fernández-Blanco [*,1], K. Kavvadias, I. Hidalgo González

Knowledge for the Energy Union Unit, Joint Research Centre, European Commission, Westerduinweg 3, NL-1755 LE Petten, Netherlands

HIGHLIGHTS

- Water-energy nexus of the Greek power system is analysed based on historical data.
- The hydrological LISFLOOD and power system Dispa-SET models are used.
- Comparison of water values with those provided by the Hellenic market operator.
- Freshwater can be stressed in dry hydrological years due to cooling of thermal plants.

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ABSTRACT

The scientific and policy relevance of the water-energy nexus in the power system is expected to increase in the future due to climate changes. The operation of the power system is constrained by the availability of water resources, which are necessary for hydropower generation and cooling thermal power plants. At the same time, water availability for non-energy purposes is affected by the power system requirements. In order to analyse this complex interdependency, this paper proposes an interdisciplinary modelling framework including the link of a hydrological model (LISFLOOD) and a power system model (Dispa-SET) within the WATERFLEX project, which aims at assessing the potential of hydropower as a source of flexibility to the European power system, as well as analysing the water-energy nexus against the background of the European Union initiatives towards a low-carbon energy system. Specifically, this paper focuses on the power system model used in WATERFLEX, which encompasses a medium-term hydrothermal coordination model (Dispa-SET MTHC) and a unit commitment and dispatch model (Dispa-SET UCD). The proposed approach is applied to the Greek power system to analyse the implications of different hydrological historical scenarios on the power system operation and economics, as well as the effect of the power system operation on the water availability. For this case study, this paper quantifies the generation costs, the environmental impacts, the water consumptions and withdrawals, as well as the water stress at different power plant locations throughout a year.

1. Introduction

1.1. Motivation

The water-energy nexus can be defined as the interdependency among different sectors, mainly water and energy sectors. This concept is formally defined by Santhosh et al. [1] as a 'system-of-systems composed of one infrastructure system with the artifacts necessary to describe a full energy value chain and another infrastructure system with the artifacts necessary to describe a full water value chain'. In this paper, we focus on the water-energy nexus in power systems [2,3], i.e., how the water system would impact on the power system operation and economics and how the resulting operation would itself affect the water availability. Specifically, the operation of the power system is constrained by the availability of water resources, which are necessary for cooling thermal power plants and thus determining the generation of hydropower plants such as reservoirs and run-of-river power plants. The interactions between the water and power system have impacts on the quantity and quality of the water resources, thus affecting human uses and the environment [4,5].

* Corresponding author.
E-mail addresses: Ricardo.FERNANDEZ-BLANCO-CARRAMOLINO@ec.europa.eu (R. Fernández-Blanco), Konstantinos.KAVVADIAS@ec.europa.eu (K. Kavvadias), Ignacio.HIDALGO-GONZALEZ@ec.europa.eu (I. Hidalgo González).
[1] The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

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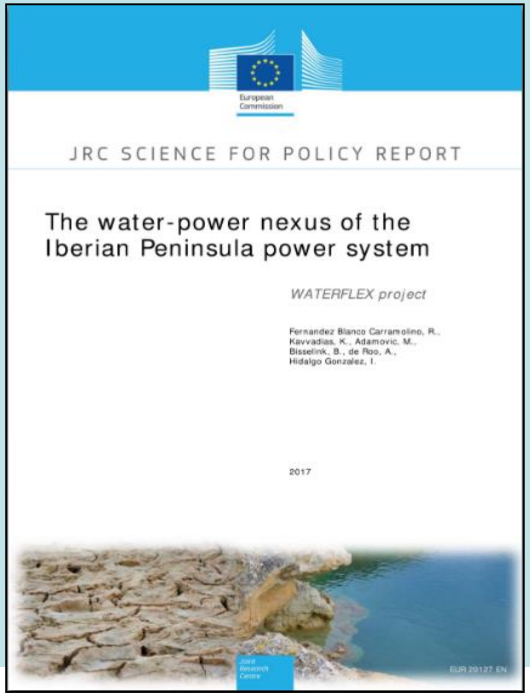
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JRC SCIENCE FOR POLICY REPORT

The water-power nexus of the Iberian Peninsula power system

WATERFLEX project

Fernandez Blanco Carramolino, R.,
Kavvadias, K., Adamovic, M.,
Bisselink, B., de Roo, A.,
Hidalgo Gonzalez, I.

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Current work streams

Modelling of the water-energy nexus at continental scale

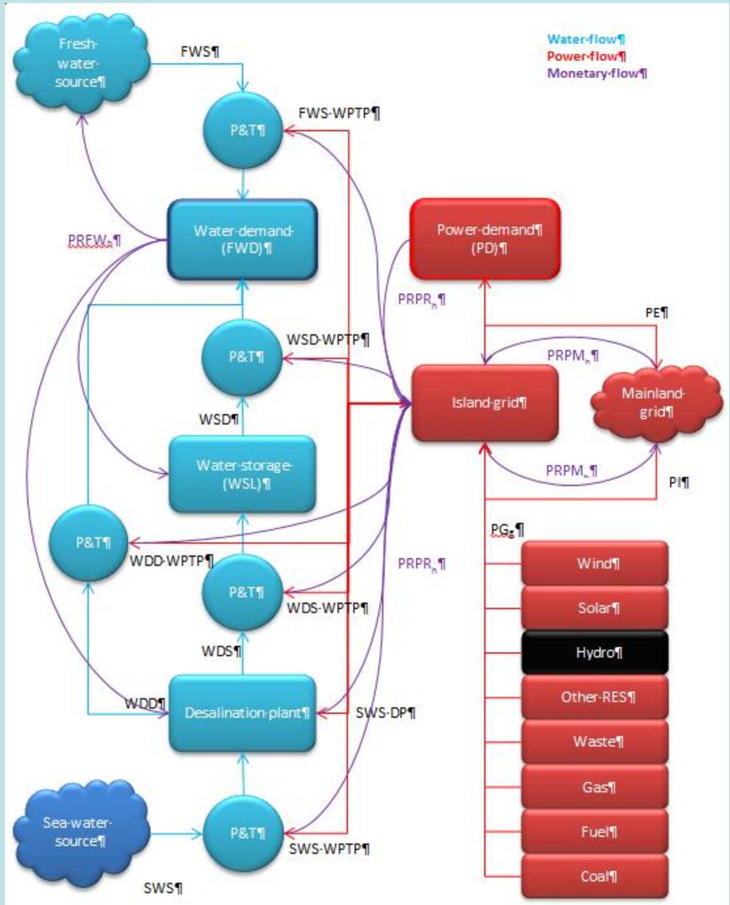
Modelling of the water-power nexus at regional (multi-country) scale

Modelling of the water-energy nexus at smaller scales (islands)

Modelling the water-energy nexus at smaller scales: approach

Goal: to study the water-energy nexus in "small" systems, such as EU islands where significant desalination capacity is needed (e.g. Baleares Islands)

- Maximise the profit of the combined water-energy system
- Constraints on
  - Fresh water balance
  - Water storage balance
  - Power balances (with and without interconnections)
  - Water flows and storage
  - Desalination capacity
  - Power (energy) system constraints



Modelling the water-energy nexus at smaller scales: data needs and sources

Power system data

- Characterisation of power plants, renewable profiles, power loads and interconnections with the island system
- Fuel prices
- Regulated and market power prices

Other energy system data

- Characterisation of other energy infrastructure (refineries, mines)

Water system data

- Available supply
- Total and sectoral demand
- Water tariffs
- Water infrastructure and desalination plants

Modelling the water-energy nexus at smaller scales: expected results

Power system

- Power plant scheduling and dispatches
- Imports and exports from mainland grid
- Revenues and costs from power generation
- Water values

Other energy system (refineries, mines)

- Water use

Water system data

- Fresh water supply schedules
- Storage levels
- Revenues and costs from water supply

Some challenges and open issues

Model-related

- Finding the right tradeoff between model complexity and "better" results
- Implementing a smooth interaction between models

Data-related

- Availability and coverage: water sector (infrastructure and demand), non-power energy sectors
- Quality: gaps, frequency, length of the time series, inconsistencies and uncertainties

We hope that this workshop will help us to obtain some insights on how to overcome these challenges!

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Thanks

Any questions?

You can find me at Ignacio.HIDALGO-GONZALEZ@ec.europa.eu