What is the value of demand-response in power systems? Insights from a hydropower viewpoint

Julien Ancel (CEC)

Olivier Massol (IFP School)

Preliminary results

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Agenda

Background

- Increasing share of intermittent RES $\longrightarrow$ Reduced flexibility on the supply-side of power markets
- Definition: flexibility $\longrightarrow$ "*The ability of a power system to reliably and **cost-effectively** manage the variability and **uncertainty** of demand and supply across all relevant timescales, from ensuring instantaneous stability of the power system to supporting long- term **security of supply***" (IEA)
- Demand response (DR) $\longrightarrow$ **Accepted** variation of power demand from its **usual pattern** in response to some **incentive/signal.**

Literature

- Small scale DR: technological opportunities (e.g. Wai et al. [2015] for cooling devices) and load scheduling of *one* end-user (Ferreira et al. [2012])
- Design of the DR incentive/price-signal: emergence of a new actor, the DR aggregator (Chapman et al. [2016]) → **Acceptance** of DR
- Assessment of DR deposits at system level (Gils [2014], Müller and Möst [2018])
- Short term operations of aggregated DR at system level with intermittent RES (Papavasiliou and Oren [2014])
- Optimal expansion planning on the long run with investment in RES and DR (Marañón-Ledesma and Tomasgard [2019])
- Only one study with bottom-up DR description and long-term operations: Verrier [2018] and the case of France in 2015. → Relatively low RES shares

Our research question

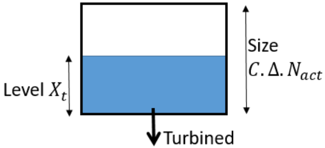
What impact does DR have on the functioning of present/future power systems?

- Interactions with other production/storage means
- Effects on market prices, security of supply and CO_2 emissions
- Differences between DR technologies

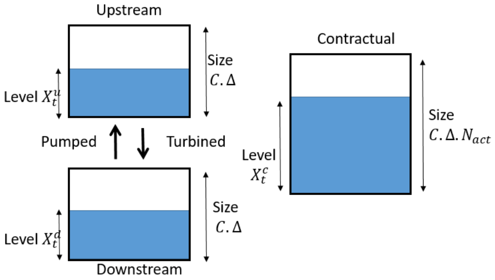
$\longrightarrow$ Optimal hourly operations of a large-scale power system with different generation technologies and an explicit representation of DR

Modelling DR – a Hydropower viewpoint

Two classical approaches: elastic demand function and **negative generation.**



(a) Load shedding



(b) Load shifting

A simple linear model of electric system

- Main ingredients:
  - Uncertain load and RES generation $\longrightarrow$ **Stochastic** Residual Demand
  - No network constraints
  - A representative plant for each technology (Nuclear, Lignite, Coal, CCGT, OCGT, Hydro, PHS)
  - Flexibility tools: Load-shedding, Load shifting, PHS

$\Longrightarrow$ A Multi-stage stochastic optimization problem :

- **Objective**: Min. E(total annual operating cost of the system)

$$\min_{u_1 \in \mathcal{U}_1(X_1, D_1)} \left(C_1 + \mathbb{E}\left[\min_{\substack{u_2 \in \mathcal{U}_2(X_2, D_2) \\ X_2 = F(X_1, u_1)}} \left(C_2 + \ldots + \mathbb{E}\left[\min_{\substack{u_T \in \mathcal{U}_T(X_T, D_T) \\ X_T = F(X_{T-1}, u_{T-1})}} C_T \right] \right) \right] \right) \tag{1}$$

  - Constraints: Power balance, Capacity constraints, Hydro/DR reservoir sizes
  - Decision variables: continuous

Stochastic Dual Dynamic Programming, a review

- Multistage
- Convex (objective) - Linear (constraints, dynamics)
- Noise : **stagewise independent** $+$ values in a finite state (but may be large)

Method: Build approximates of Bellman functions as suprema of affine functions with slope computed thanks to the dual variable of a state constraints in subproblems

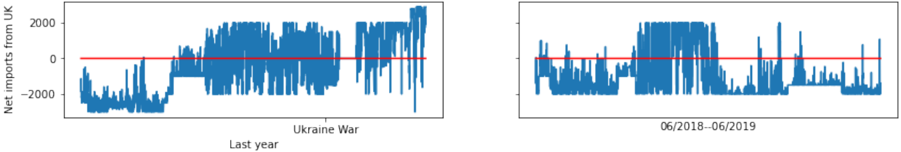
$$V_t(x) = \mathbb{E}\left[\min_{u \in \mathcal{U}_t(x, D_t)} C_t(x, u, D_t) + V_{t+1} \circ f_t(x, u, D_t)\right]$$

Pros: Ability to handle large sets of values of noise with reduced computational effort **+** Yields approximate opportunity costs **+** Good theoretical properties (on convergence and quality of approximation).

Cons: The ”curse of dimensionality” (as state space increases).

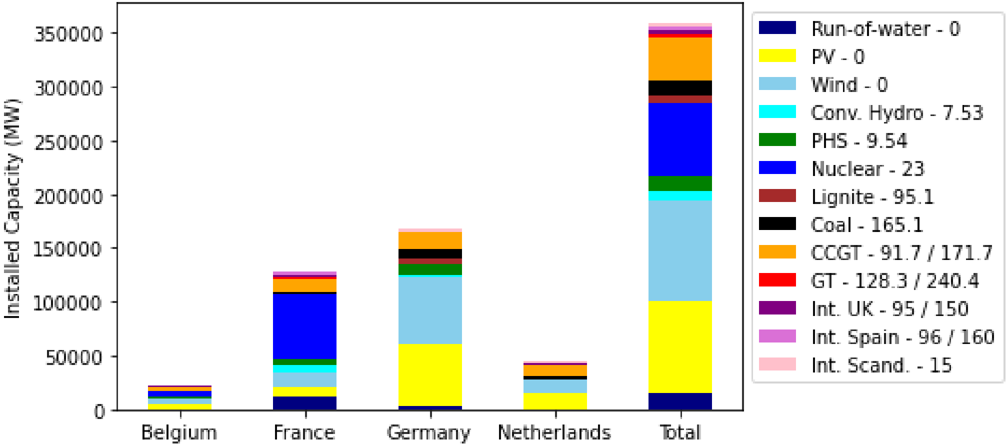
Application — Northwestern Europe in 2023

- High gas prices **&** ~80€/tCO_2 carbon price $\longrightarrow$ Coal attractive again.
- Cheaper gas exports through power interconnections $\longrightarrow$ Modified pattern of exchanges



Does DR integration affect the total system cost, power prices and the system's environmental performance?

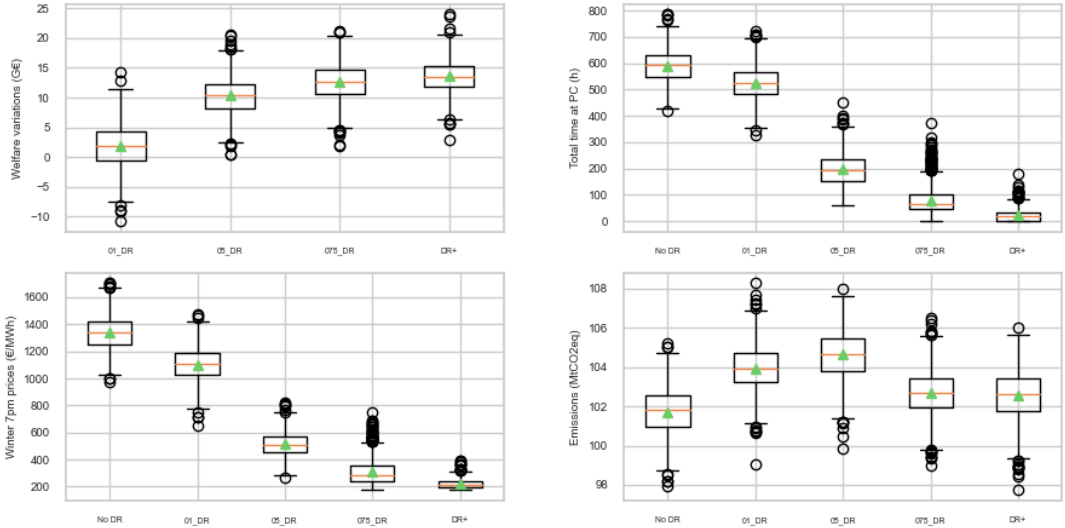
NWE Power Mix



NWE Demand Response Potentials

Technology	**Installed capacity (MW)**	**Activation cost (€/MWh)**	**Event duration (h)**	**Number of activations**
Steel - electric furnace	2222	411	4	50
Aluminium - electric furnace	447	164	4	50
Chlorine electrolysis	1366	96	4	50
Cement mills	1083	10	3	260
Paper and pulp	2062	10	3	260
Industrial cooling	3166	16	1	364
Industrial cross-tech ventilation	693	16	1	364
Tertiary cooling	39753	11	1	364
Tertiary heating	47042	11	4	364
Residential cooling	30460	11	1	364
Residential heating	7052	11	1	364

Multi-faceted impacts of DR



Main findings

- Positive effect of DR on the system $\longrightarrow$ better security of supply, positive welfare variation. But effect on emissions depends on the most expensive generation mean.
- Combination load-shifting $+$ PHS partially suppresses call to thermal plants and reduce needs for imports. Some load-shedding technologies can compete with peak thermal plants.
- From the aggregator point of view: business mainly profitable
- But, in some scenarios, possible negative total profits
- All DR deposits are not equivalent in terms of profits for the aggregator $\longrightarrow$ Risk of cherry picking profitable deposits $\neq$ System interest for flexibility

Limitations & Future works

- A spatial extension: with a national node for each member of the European power grid (31) to model interconnections and spatial arbitrages.

- Spatial dis-aggregation below country-level and network constraints in order to explore the effect and value of demand response as an help to prevent from network congestion.
  But need to spatially disaggregate the DR deposits and their availability (notably account for climate differences).