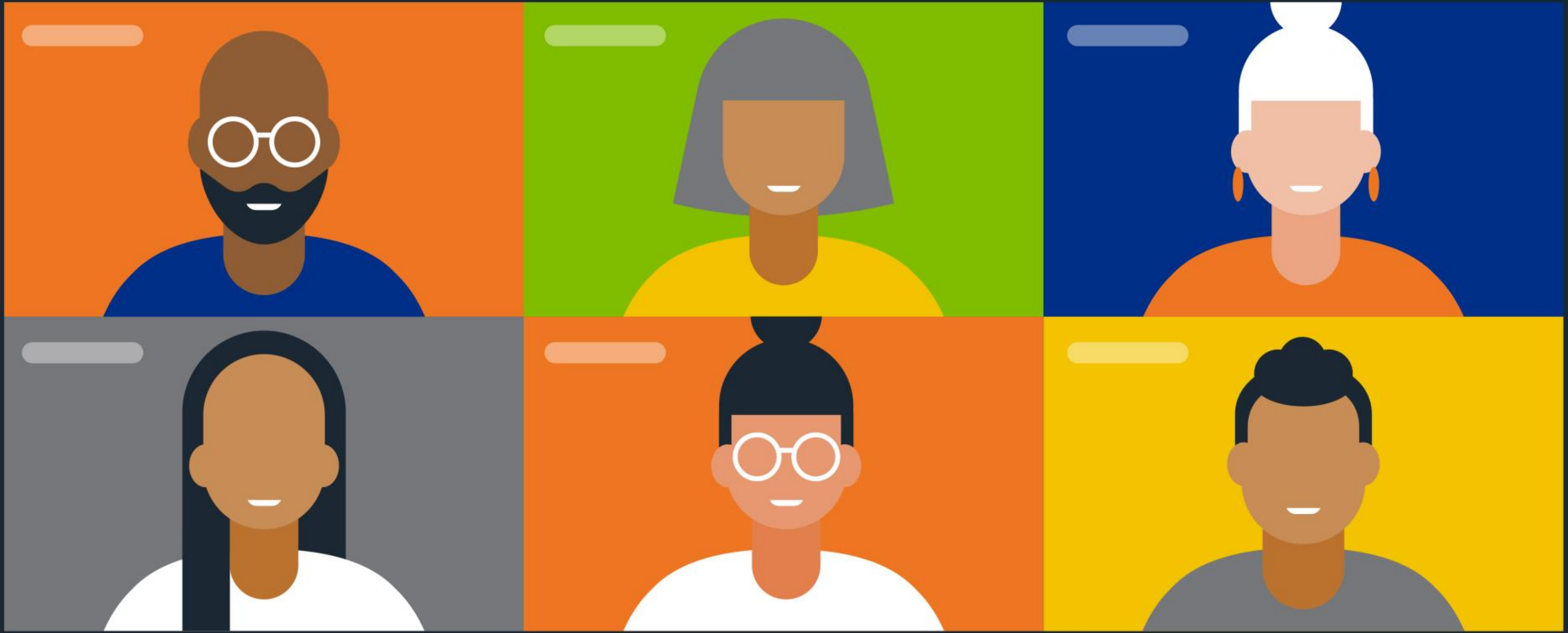

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Affine Decision Rule Approximation to Immunize against Demand Response Uncertainty in Smart Grids' Capacity Planning

Sajad Aliakbari Sani
Joint work with Olivier Bahn and Erick Delage

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Outline

i. Introduction

ii. Generation expansion planning (GEP), ETEM

iii. Robust ETEM

iv. Decomposition algorithm

v. Numerical results

Introduction- GEP problem

Generation Expansion Planning (GEP) problem:

- Optimal investment plan for generation technologies

$$\min_{x_t^i, y_t} \sum_{t,i} \rho_t \cdot [I_t(x_t^i) + F_t(x_i^t) + V_t(y_t)]$$

$$g_t(x_i^t, y_t) \geq b_t$$

$$x \in \mathcal{X}, y \in \mathcal{Y}$$

Definition	
x_t^i	Investment of technology i in period t
x_i^t	Installed capacity of technology i up to period t
y_t	Procurement decision at period t
I_t	Investment cost
F_t	Fixed operational cost
V_t	Variable operational cost
$g_t(x, y_t)$	Network balance constraints

- It is a challenging problem:
    - Large scale problem
    - Presence of uncertainties

Introduction - DR

Demand Response: "Changes in electric usage by end-use customers in response to supply side incentives[1]"

DR is an alternative for expensive capacity expansion policies

Recent versions of Smart grid's GEP consider demand response (DR)

$$\min_{x_t^i, y_t, \bar{d}_t} \sum_{t,i} \rho_t \cdot [I_t(x_t^i) + F_t(x_i^t) + V_t(y_t)]$$

$$g_t(x_i^t, y_t, \bar{d}_t) \geq b_t$$

$$x \in \mathcal{X}, y \in \mathcal{Y}$$

[1] Energy Regulatory Commission

Introduction - DRU

Integrating DR in GEP is challenging because:

- Availability of resource depends on level of contribution to DR programs;
- Level of contribution is not known at the planning phase;

Failure to address DRU leads to inappropriate installed capacity; i.e. either shortage of electricity or wasted excess capacity.

Robust Optimization (RO) and Stochastic Programming (SP) are two main tools to address DRU.

[1] Energy Regulatory Commission

Introduction - RO

- Robust Optimization (RO) is an approach to address uncertainty when the distribution of parameters is not known.

- The uncertain parameters are only known to lie within a region, called uncertainty set, and the purpose is to identify solutions that are immune with respect to realizations of the uncertain parameters.

$$\min_{x \in \mathcal{X}} \max_{z \in \mathcal{Z}} h(x, z)$$
$$s.t.\ g_j(x, z) \geq 0,\ \forall z \in \mathcal{Z}, \forall j = 1, \cdots, J$$

- Solutions obtained from RO are guaranteed to have the best performance in worst-case scenario of the uncertain parameter.

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Introduction – MPRO

Multi-period RO (MPRO) refers to problems in which decisions are taken at different points of time:

- ***Here and now*** decisions need to be taken before any information about uncertainty is revealed.
- ***Recourse*** decisions could be delayed until after observing the realizations of all uncertain parameters.
- The purpose is to make the best first-stage decision assuming the worst cost will occur for the next period.

$$\max_{x_1,\{x_t(\cdot)\}_{t=2}^{T}} \quad \inf_{z\in\mathcal{Z}} \; c_1(z)^\top x_1 + \sum_{t=2}^{T} c_t(z)^\top x_t(v_t(z))$$

subject to:

$$a_{j1}(z)^\top x_1 + \sum_{t=2}^{T} a_{jt}(z)^T x_t(v_t(z)) \leq b_j(z), \quad \forall z \in \mathcal{Z}, \forall j = 1, \cdots, J$$

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ETEM – generation expansion model

- Energy-Technology-Environment-Model (ETEM)[1]
- Long term capacity expansion planning model.
  - Planning horizon: 50 years
- Large scale linear programming
- Objective: minimize total cost of capacity expansion planning:
  - Investment cost
  - Fixed cost
  - Variable cost
  - Importation cost
  - Exportation income
  - Transmission cost
- Constraints: technology constraint, network energy balance, demand response constraint, economical and environmental constraints.

[1] F. Babonneau, M. Caramanis, A. Haurie, Etem-sg: Optimizing regional smart energy system with power distribution constraints and options, Environmental Modeling & Assessment 22 (2017) 411–4

ETEM – Demand response constraint

$$\sum_{p \in \mathbb{P}^{P_c}} \boldsymbol{P}_{t,s,l,p,c} \geq \Theta_{t,l,c} \boldsymbol{V}_{t,s,c} \; \forall t, s, l, c \in \mathbb{C}^{\mathcal{D}}$$

Definition	
$\Theta_{t,l,c}$	Annual demand
$\upsilon_{t,s,c}$	Nominal DR
$\nu_{t,s,c}$	Allowed deviation from nominal DR
$\mathcal{S}_j$	All time-slices in season j
$\mathbb{J}$	Set of all seasons
$\mathbb{P}^{P_c}$	Set of all technologies producing c
$\mathbb{P}^{C_c}$	Set of all technologies consuming c
$c \in \mathbb{C}^{\mathcal{D}}$	Demand
$\boldsymbol{P}_{t,s,l,p,c}$	Production
$\boldsymbol{V}_{t,s,c}$	Planned DR

Robust DR:

$$\sum_{p \in \mathbb{P}^{P_c}} \boldsymbol{P}_{t,s,l,p,c} \geq \Theta_{t,l,c} \left(\boldsymbol{V}_{t,s,c} + \delta_{t,s,c} \right) \quad \forall \delta \in \Delta \quad \forall t, s, l, c \in \mathbb{C}^{\mathcal{U}}$$

Budget uncertainty set:

$$\Delta = \left\{ \delta \in \mathbb{R}^d \middle| \exists \zeta \in [-1, 1]^d, \; \delta_{t,s,c} = \beta_{t,s,c} \zeta_{t,s,c}, \; \forall t, s, c \in \mathbb{C}^U, \sum_{s \in \mathbb{S}^j} \sum_{c \in \mathbb{C}^U} |\zeta_{t,s,c}| \leq \Gamma_{t,j} \; \forall t, j \in \mathbb{J} \right\}$$

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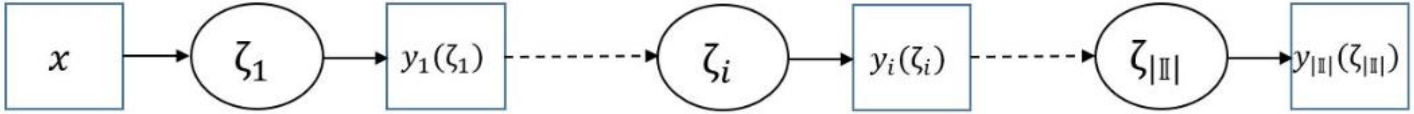
RETEM – Decision making chronology



- First-stage decision (X)
  - Capacity expansion plan
  - Planned demand response

$$x = [\boldsymbol{C}_{t,l,p}, \boldsymbol{C}^{T}_{t,l,p}, \boldsymbol{V}_{t,s,c}]^{\top} \ \forall t, s, l, p, c \in \mathbb{C}^{\mathcal{D}}$$

- Seasonal periodic decisions (y_i)
  - Energy production
  - Energy import and export
  - Regional transmission

$$y_i = [\boldsymbol{P}_{t,s,l,p,c}, \boldsymbol{T}_{t,s,l,l' \neq l,c}, \boldsymbol{I}_{t,s,l,c}, \boldsymbol{E}_{t,s,l,c}]^{\top} \ \forall (t,s) \in \mathscr{A}_i, l, p, c$$

RETEM – Problem formulation

Multi-period adjustable formulation:

$$\begin{aligned}
\min_{\boldsymbol{x},\{\boldsymbol{y}_i\}_{i=1}^{|\mathbb{I}|}} \quad \max_{\{\boldsymbol{\zeta}_i\in\mathcal{Z}_i\}_{i=1}^{|\mathbb{I}|}} \quad & f^\top \boldsymbol{x} + \sum_{i=1}^{|\mathbb{I}|} h_i^\top \boldsymbol{y}_i(\boldsymbol{\zeta}_i) \\
s.t. \quad & A_i\boldsymbol{x} + B_i\boldsymbol{y}_i(\boldsymbol{\zeta}_i) \leq b_i + C_i\boldsymbol{\zeta}_i \quad \forall \boldsymbol{\zeta}_i \in \mathcal{Z}_i(\Gamma_i),\ \forall i \in \{1 \dots |\mathbb{I}|\} \\
& D\boldsymbol{x} \leq e
\end{aligned}$$

Robust multi-period conservative approximation:

$$\begin{aligned}
\min_{\boldsymbol{x},\{\boldsymbol{Y}_i,\boldsymbol{y}_i\}_{i=1}^{|\mathbb{I}|}} \quad \max_{\{\bar{\boldsymbol{\zeta}}_i\in\bar{\mathcal{Z}}_i\}_{i=1}^{|\mathbb{I}|}} \quad & f^\top \boldsymbol{x} + \sum_{i=1}^{|\mathbb{I}|} h_i^\top \left(\boldsymbol{y}_i + \boldsymbol{Y}_i\bar{\boldsymbol{\zeta}}_i\right) \\
s.t. \quad & A_i\boldsymbol{x} + B_i\left(\boldsymbol{y}_i + \boldsymbol{Y}_i\bar{\boldsymbol{\zeta}}_i\right) \leq b_i + C_iP_i\bar{\boldsymbol{\zeta}}_i \quad \forall \bar{\boldsymbol{\zeta}}_i \in \bar{\mathcal{Z}}_i\ \forall i \in \{1 \dots |\mathbb{I}|\} \\
& D\boldsymbol{x} \leq e
\end{aligned}$$

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RETEM – Problem formulation

Multi-period adjustable formulation:

$$\min_{\boldsymbol{x},\{\boldsymbol{y}_i\}_{i=1}^{|\mathbb{I}|}} \max_{\{\boldsymbol{\zeta}_i \in \mathcal{Z}_i\}_{i=1}^{|\mathbb{I}|}} f^\top \boldsymbol{x} + \sum_{i=1}^{|\mathbb{I}|} h_i^\top$$

$$s.t. \quad A_i \boldsymbol{x} + B_i \boldsymbol{y}_i(\boldsymbol{\zeta}$$

$$D\boldsymbol{x} \leq e$$

Robust multi-period conser

$$\min_{\boldsymbol{x},\{\boldsymbol{Y}_i,\boldsymbol{y}_i\}_{i=1}^{|\mathbb{I}|}} \max_{\{\bar{\boldsymbol{\zeta}}_i \in \bar{\mathcal{Z}}_i\}_{i=1}^{|\mathbb{I}|}} f^\top \boldsymbol{x} + \sum_{i=}^{|\mathbb{I}}$$

$$s.t. \quad A_i \boldsymbol{x} + B_i\left(\boldsymbol{y}_i + \boldsymbol{Y}_i \bar{\boldsymbol{\zeta}}_i\right) \leq b_i + C_i P_i \boldsymbol{\zeta}_i \quad \forall \boldsymbol{\zeta}_i \in \mathcal{Z}_i \; \forall i \in \{1 \ldots |\mathbb{I}|\}$$

$$D\boldsymbol{x} \leq e$$

Final reformulated problem:

$$\begin{aligned}
\min_{\mathbf{x},\{\boldsymbol{\theta}_i,\boldsymbol{\Phi}_i,\mathbf{Y}_i,\mathbf{y}_i\}_{i=1}^{\tau}} \quad & f^\top \mathbf{x} + \sum_{i=1}^{\tau} \nu_i^\top \boldsymbol{\theta}_i + h_i^\top \mathbf{y}_i \\
s.t. \quad & D\mathbf{x} \leq e \\
& W_i^\top \boldsymbol{\theta}_i = (h_i^\top \mathbf{Y}_i)^\top \quad \forall i \in \{1, .., \tau\} \\
& \boldsymbol{\Phi}_i \nu_i \leq b_i - A_i \mathbf{x} - B_i \mathbf{y}_i \quad \forall i \in \{1, .., \tau\} \\
& \boldsymbol{\Phi}_i W_i = B_i \mathbf{Y}_i - C_i P_i \quad \forall i \in \{1, .., \tau\} \\
& \boldsymbol{\Phi}_i, \boldsymbol{\theta}_i \geq 0
\end{aligned}$$

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Decomposition algorithm

Remember the structure of the approximation problem:

- Separable constraint (2)
- Separable second stage variable $\boldsymbol{y}_i$ and $\boldsymbol{Y}_i$
- Coupling variable $\boldsymbol{x}$ and constraint (3)

Robust Multi Period Conservative Approximation

$$\min_{\mathbf{x},\{\mathbf{Y}_i,\mathbf{y}_i\}_{i=1}^{|\mathbb{I}|}} \max_{\{\bar{\zeta}_i \in \bar{\mathcal{Z}}_i\}_{i=1}^{|\mathbb{I}|}} f^\top \mathbf{x} + \sum_{i=1}^{|\mathbb{I}|} h_i^\top \left(\mathbf{y}_i + \mathbf{Y}_i \bar{\zeta}_i\right) \tag{1}$$

$$s.t. \quad A_i \mathbf{x} + B_i \left(\mathbf{y}_i + \mathbf{Y}_i \bar{\zeta}_i\right) \leq b_i + C_i P_i \bar{\zeta}_i \quad \forall \bar{\zeta}_i \in \bar{\mathcal{Z}}_i \; \forall i \in \{1 \ldots |\mathbb{I}|\} \tag{2}$$

$$D\mathbf{x} \leq e \tag{3}$$

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Decomposition algorithm

Presentation of RMPCA in master-sub problems format

The (RMPCA) is equivalent to :

$$(\mathrm{MP}) \quad \min_{\mathbf{x},\boldsymbol{\rho},\{\mathbf{y}_i\}_{i=1}^{\mathcal{T}}} f^\top \mathbf{x} + \sum_{i=1}^{\mathcal{T}} h_i^\top \mathbf{y}_i + \boldsymbol{\rho}_i$$

$$\begin{aligned} s.t. \quad & D\mathbf{x} \leq e \\ & \boldsymbol{\rho}_i \geq g_i(\mathbf{x}, \mathbf{y}_i) \quad \forall i \in \{1..\mathbb{I}\} \\ & A_i\mathbf{x} + B_i\mathbf{y}_i \leq b_i \quad \forall i \in \{1..\mathbb{I}\} \end{aligned}$$

Where:

$$(\mathrm{SP}_i) \quad \min_{\mathbf{Y}_i} \max_{\{\bar{\zeta}_i \in \bar{\bar{\mathcal{Z}}}_i\}_{i=1}^{|\mathbb{I}|}} h_i^\top \mathbf{Y}_i \bar{\zeta}_i$$

$$s.t. \quad A_i\mathbf{x} + B_i\left(\mathbf{y}_i + \mathbf{Y}_i\bar{\zeta}_i\right) \leq b_i + C_iP_i\bar{\zeta}_i \quad \forall \bar{\zeta}_i \in \bar{\mathcal{Z}}_i \; \forall i \in \{1...|\mathbb{I}|\}$$

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Decomposition algorithm

Presentation of RMPCA in master-sub problems format

The (RMPCA) is equivalent to :

$$
\begin{aligned}
\text{(MP)} \quad & \min_{\mathbf{x},\boldsymbol{\rho},\{\mathbf{y}_i\}_{i=1}^{\mathcal{T}}} f^\top \mathbf{x} + \sum_{i=1}^{\mathcal{T}} h_i^\top \mathbf{y}_i + \boldsymbol{\rho}_i \\
& s.t. \quad D\mathbf{x} \leq e \\
& \qquad \boldsymbol{\rho}_i \geq g_i(\mathbf{x}, \mathbf{y}_i) \quad \forall i \in \{1..\mathbb{I}\} \\
& \qquad A_i\mathbf{x} + B_i\mathbf{y}_i \leq b_i \quad \forall i \in \{1..\mathbb{I}\}
\end{aligned}
$$

Where:

$$
\begin{aligned}
(\text{SP}_i) \quad g_i(x, y_i) = & \max_{\boldsymbol{\theta}_i \geq 0, \bar{\zeta}_i \geq 0, \boldsymbol{\lambda}_i \geq 0} (-b_i + A_i x + B_i y_i)^\top \boldsymbol{\theta}_i - Tr(C_i P_i \boldsymbol{\lambda}_i) \\
& s.t. \quad \boldsymbol{\theta}_i \nu_i^\top - \boldsymbol{\lambda}_i W_i^\top \geq 0 \\
& \qquad B_i^\top \boldsymbol{\lambda}_i = -h_i \bar{\zeta}_i^\top \\
& \qquad W_i \bar{\zeta}_i \leq \nu_i
\end{aligned}
$$

Decomposition algorithm

Presentation of RMPCA in master-sub problems format

The (RMPCA) is equivalent to :

$$
\begin{aligned}
\text{(MP)} \quad & \min_{\mathbf{x},\boldsymbol{\rho},\{\mathbf{y}_i\}_{i=1}^{\mathcal{T}}} f^\top \mathbf{x} + \sum_{i=1}^{\mathcal{T}} h_i^\top \mathbf{y}_i + \rho_i \\
& s.t. \quad D\mathbf{x} \le e \\
& \qquad\quad \rho_i \ge g_i(\mathbf{x}, \mathbf{y}_i) \quad \forall i \in \{1..\mathbb{I}\} \\
& \qquad\quad A_i\mathbf{x} + B_i\mathbf{y}_i \le b_i \quad \forall i \in \{1..\mathbb{I}\}
\end{aligned}
$$

Where:

$$
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& s.t. \quad \boldsymbol{\theta}_i \nu_i^\top - \boldsymbol{\lambda}_i W_i^\top \ge 0 \\
& \qquad\quad B_i^\top \boldsymbol{\lambda}_i = -h_i \bar{\zeta}_i^\top \\
& \qquad\quad W_i \bar{\zeta}_i \le \nu_i
\end{aligned}
$$

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Decomposition algorithm - Enhancement

- In order to enhance MP to improve LB, replace master problem with:

$$
\begin{aligned}
\text{(MPVI)} \quad & \min_{\mathbf{x},\{\rho_i,\mathbf{y}_i\}_{i=1}^{\mathbb{I}}} f^\top \mathbf{x} + \sum_{i=1}^{\mathbb{I}} h_i^\top \mathbf{y}_i + \rho_i \\
& s.t. \quad D\mathbf{x} \leq e \\
& \qquad A_i\mathbf{x} + B_i\mathbf{y}_i \leq b_i \quad \forall i \in \{1..\mathbb{I}\} \\
& \qquad \rho_i \geq (-b_i + A_i\mathbf{x} + B_i\mathbf{y}_i)^\top \overline{\theta}_i^v - Tr(C_i P \overline{\lambda}_i^v), \quad \forall v \in G^v, \forall i \in \{1..\mathbb{I}\} \\
& \qquad \rho_i \geq h_i^\top (\mathbf{y}_i^l - \mathbf{y}_i) \quad \forall l \in \Omega, \forall i \in \{1,..,\mathbb{I}\} \\
& \qquad A_i\mathbf{x} + B_i\mathbf{y}_i^l \leq b_i + C_i P_i \zeta_i^l \quad \forall l \in \Omega, \forall i \in \{1,..,\mathbb{I}\}
\end{aligned}
$$

- Ω is the set of last n worst-case scenarios identified in the algorithm.

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Decomposition algorithm - Enhancement

- At each iteration the master problem might have multiple solutions
- All solutions have the same worst-case performance
- But they might not have the same performance in other scenarios.
- Solve an extra optimization problem at each iteration to transmit PRO first-stage values to SPs:

$$
\begin{aligned}
\min_{\mathbf{x},\{\rho_i',\rho_i,\mathbf{y}_i\}_{i=1}^{\tau}} \quad & f^\top \mathbf{x} + \sum_{i=1}^{\tau} h_i^\top \mathbf{y}_i + \rho_i' \\
s.t. \quad & \text{All constraint of MPVI} \\
& f^\top \mathbf{x} + \sum_{i=1}^{\tau} h_i^\top \mathbf{y}_i + \rho_i \leq (1+\epsilon)\mathscr{M}_v^* \\
& \rho_i' \geq \sum_{v} \frac{1}{|G^v|}[(-b_i + A_i\mathbf{x} + B_i\mathbf{y}_i)^\top \overline{\theta}_i^v - Tr(C_i P \overline{\lambda}_i^v)] \quad \forall i \in \{1..\tau\}
\end{aligned}
$$

Decomposition algorithm - Performance

Table: Solution time (seconds) and number of iterations of different decomposition algorithms

$\mathbb{T}$	DET Problem-size		AARC Problem-size		BD		PRO-BD			PRO-BD-VI		
	Var	Con	Var	Con	CPU(S)	It	CPU(S)	It	% impr.	CPU(S)	It	% impr.
3	4,644	11,830	97,112	103,095	47.0	15	37.5	10	20%	26.0	4	45%
5	7,740	19,718	161,860	171,837	92.8	15	78.1	11	16%	68.9	5	26%
7	10,836	27,601	226,583	240,534	78.0	10	68.0	7	13%	48.0	3	39%
9	13,932	35,486	291,316	309,249	97.0	9	82.1	6	15%	81.3	3	16%
Average					78.7	12	66.4	8	16%	56.0	4	29%

- BD: Traditional Benders decomposition
- PRO-BD: Benders decomposition with pareto robust solutions
- RPO-BD-VI: Benders decomposition with PRO and Valid Inequalities

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Case study

- Energy system of Geneva Lake region in Switzerland [3]
- 140 Technologies:
  - Power-plants,
  - DGs;
  - Heat production;
  - Conventional and Flexible loads;
  - end-use transportation;
- 50 Energy commodities:
  - Resources;
  - Secondary energy;
  - final demand;
- A detailed description of final demand technologies: 100 technologies in:
  - industrial;
  - residential;
  - transportation;

[3] F. Babonneau, M. Caramanis, A. Haurie, Etem-sg: Optimizing regional smart energy system with power distribution constraints and options, Environmental Modeling & Assessment 22 (2017) 411–4

Results – Robust performance

DET: deterministic model
SRM: static robust model
RMPCA: robust multi-period conservative approximation
To obtain average expected cost:

1. Solve deterministic, AARC and Static-RC problems and store the first-stage values (x_{DET}), (x_{RMPCA}) and (x_{SRM}) respectively.
2. Generate 1000 random scenarios for $\zeta_i, \forall i = 1 \cdots \tau$ in the allowed deviation interval.
3. Fixing the values of ζ_i and x to their corresponding scenario and policy, re-optimize the second-stage variables $y_i, \forall i = 1 \cdots \tau$.

Infeasibility percentage

Γ	AARC	SRC	DET
10%	100%	100%	100%
20%	98%	96%	100%
30%	29%	0%	100%
40%	9%	0%	100%
50%	4%	0%	100%
60%	2%	0%	100%
70%	10%	0%	100%
80%	0%	0%	100%
90%	0%	0%	100%
100%	0%	0%	100%

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Results – Robust performance

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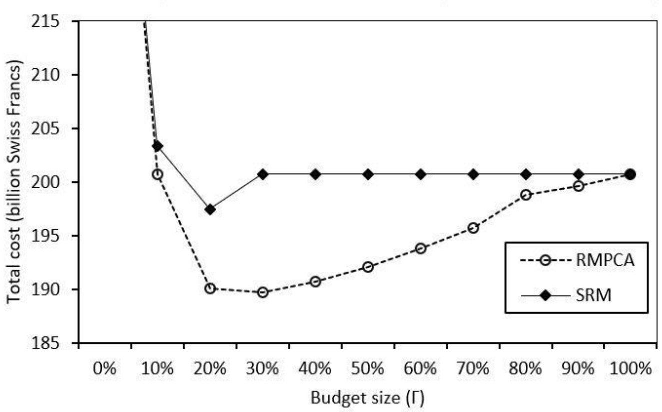
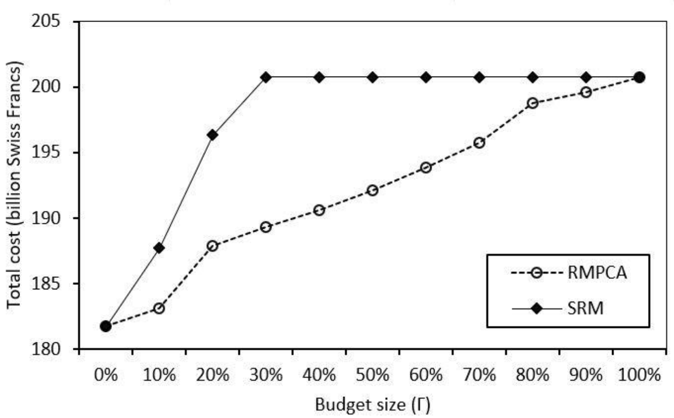
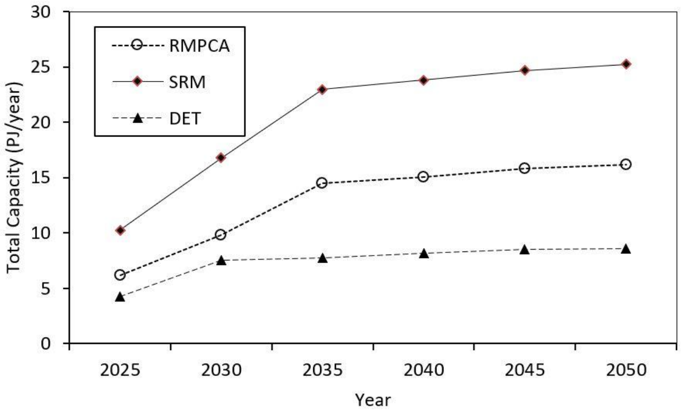




Results – Policy structure



Total installed capacity by type for AARC, SRC and DET models (MW)

	2025			2030			2035			2040			2045			2050		
	RMPCA	SRM	DET	RMPCA	SRM	DET	RMPCA	SRM	DET	RMPCA	SRM	DET	RMPCA	SRM	DET	RMPCA	SRM	DET
Hydro-PP	21.3	21.3	18.9	22.4	22.4	22.4	22.4	22.4	22.4	22.6	22.6	22.6	22.8	22.8	22.8	23	23	23
PV-PP	0.2	0.2	0.2	0.2	0.2	0.2	0.8	0.8	0.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Wind-PP	168.4	297.6	110.8	282.5	504.1	211.3	431.1	697.3	216.5	446.2	721.9	230.0	471.2	750.1	239.1	480.9	767.2	240.7
CHP	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Other[1]	0.5	0.5	0.5	1.2	0.5	0.5	1.2	3.1	0.5	1.2	3.1	0.5	1.2	3.1	0.5	3.1	3.1	3.1

[1] Other includes geothermal,fuel-cell and municipal-waste power plants

Summary

- We solved a robust multi-period conservative approximation of generation expansion model with uncertain DR.
- In the first stage the planner decides on capacity expansion strategy and planned DR.
- In seasonal stages, after observing the actual DR, the planner decides on optimal procurement of energy.
- An enhanced version of Bender's decomposition algorithm was proposed to increase the solution efficiency.
- The proposed adjustable approach can reduce the average expected cost of the system by 30% while keeping the infeasibility rate as low as 2%.
- The proposed decomposition solution method can efficiently solve realistic large-scale robust-ETEM model.

Thank you for your attention!

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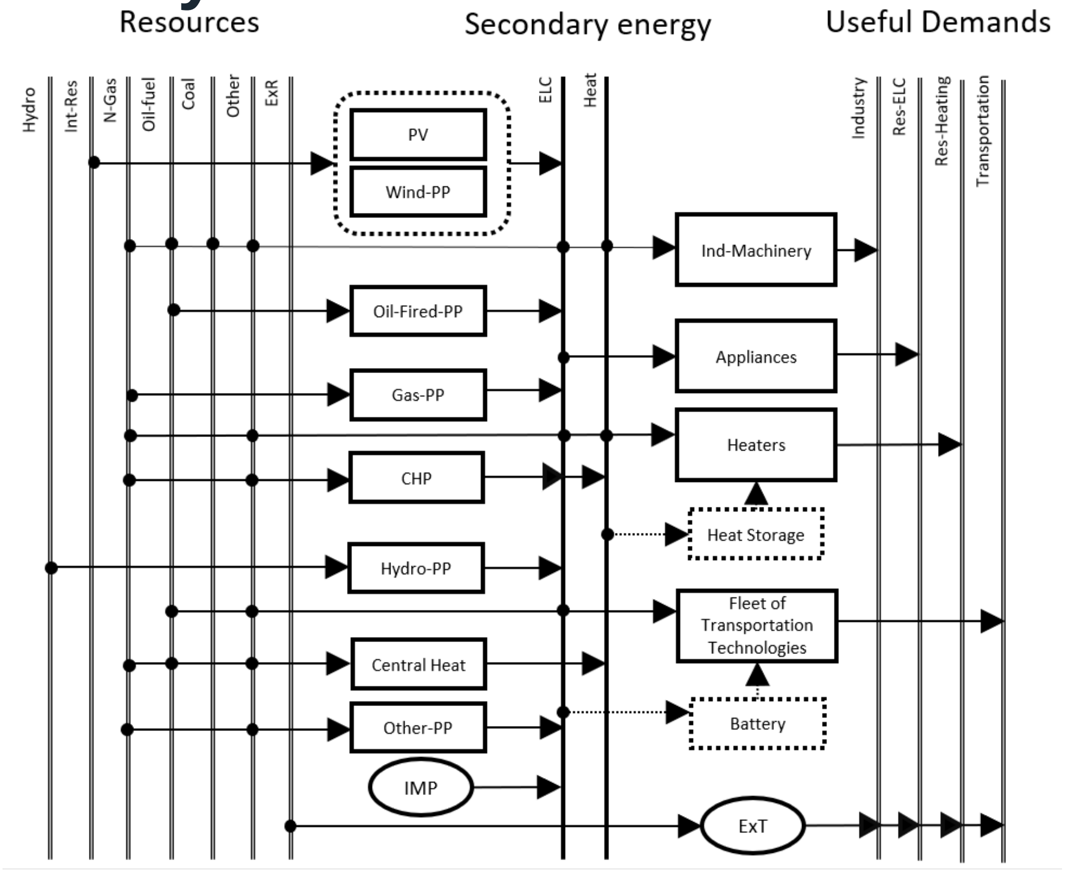
Case study


Resources
Secondary energy
Useful Demands
Hydro
Int-Res
N-Gas
Oil-fuel
Coal
Other
ExR
ELC
Heat
Industry
Res-ELC
Res-Heating
Transportation
PV
Wind-PP
Ind-Machinery
Oil-Fired-PP
Appliances
Gas-PP
Heaters
CHP
Heat Storage
Hydro-PP
Fleet of Transportation Technologies
Central Heat
Battery
Other-PP
IMP
ExT

RETEM – Seasonal uncertainty set

We are using a lifted uncertainty set:

$$\mathcal{Z}_i = P_i \bar{\mathcal{Z}}_i \, ,$$

$$\bar{\mathcal{Z}}_i = \left\{ \bar{\zeta}_i \in R^{r_i} \,\middle|\, W_i \bar{\zeta}_i \leq \nu_i, \bar{\zeta}_i \geq 0 \right\}$$

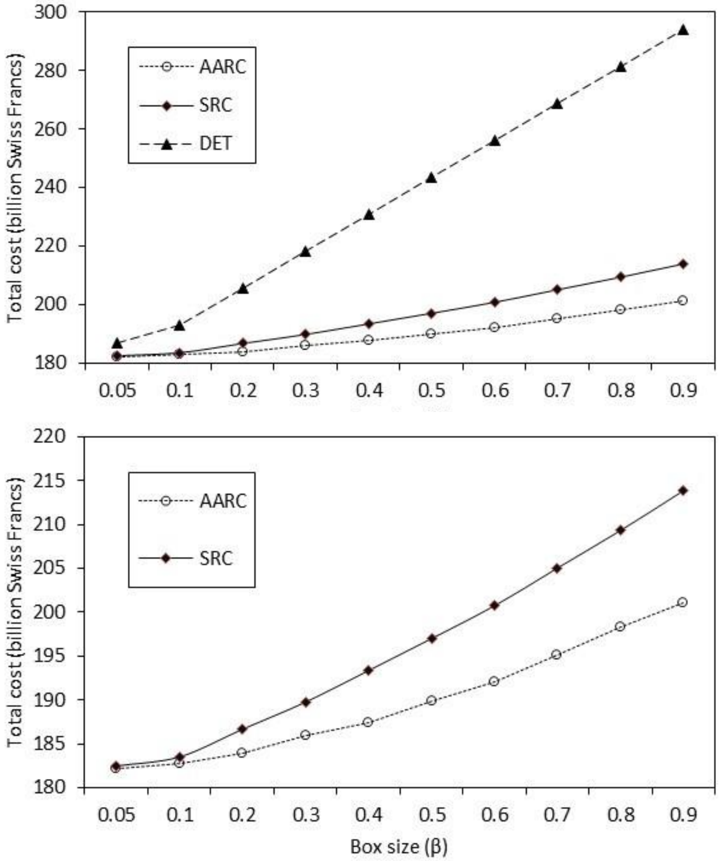
With true definition of matrices:

$$W_i := \begin{bmatrix} I_{d_i} & I_{d_i} \\ \mathbf{1}_{1\times d_i} & \mathbf{1}_{1\times d_i} \end{bmatrix} \qquad \nu_i := \begin{bmatrix} \mathbf{1}_{d_i\times 1} \\ \Gamma_i \end{bmatrix} \qquad P_i := \begin{bmatrix} I_{d_i} & -I_{d_i} \end{bmatrix}$$

Results – Robust performance

DET: deterministic model
SRC: static robust counterpart
AARC: affinely adjustable robust counterpart
To obtain average expected cost:

1. Solve deterministic, AARC and Static-RC problems and store the first-stage values (x_{DET}), (x_{AARC}) and (x_{SRC}) respectively.
2. Generate 1000 random scenarios for $\zeta_i, \forall i = 1 \cdots \tau$ in the allowed deviation interval.
3. Fixing the values of ζ_i and x to their corresponding scenario and policy, re-optimize the second-stage variables $y_i, \forall i = 1 \cdots \tau$.



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